Associations between motor and cognitive functioning in school-aged children

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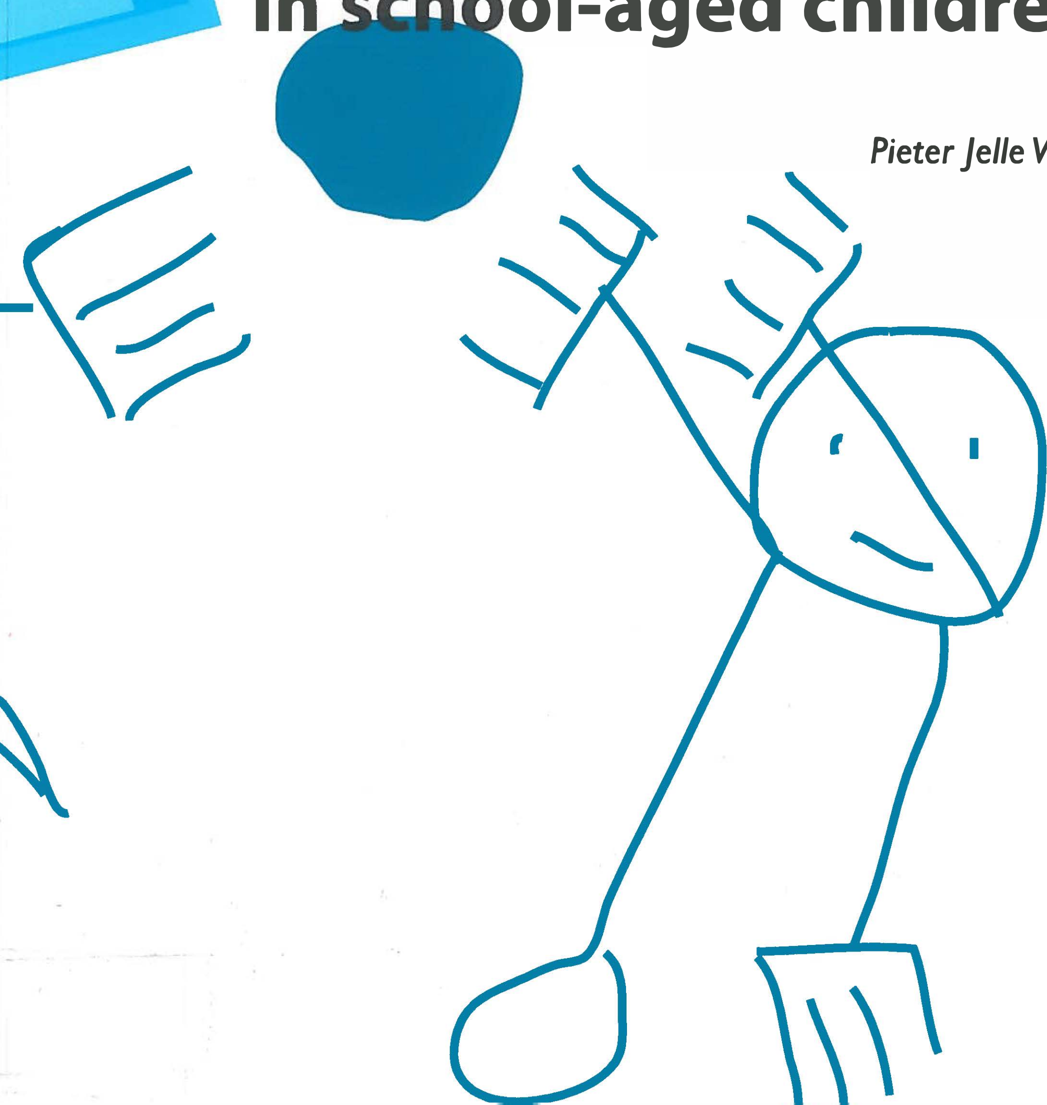


Associations between motor and cognitive functioning in school-aged children

Pieter Jelle Vuijk

Stellingen

behorende bij het proefschrift:

Associations between motor and cognitive functioning in school-aged children

Pieter Jelle Vuijk

1. Motorisch functioneren en cognitie zijn onlosmakelijk met elkaar verbonden (dit proefschrift).

2. Hoe fijner de beweging hoe opvallender het probleem (dit proefschrift).

3. Van basketballen word je slimmer dan van hardlopen (dit proefschrift).

4. Het verbeteren van cognitief functioneren kan bereikt worden door meer te bewegen en meer je handen te gebruiken (dit proefschrift).

5. Het onderwijzen op het speciaal basisonderwijs is vergelijkbaar met topsport en heeft een positief effect op cognitieve flexibiliteit.

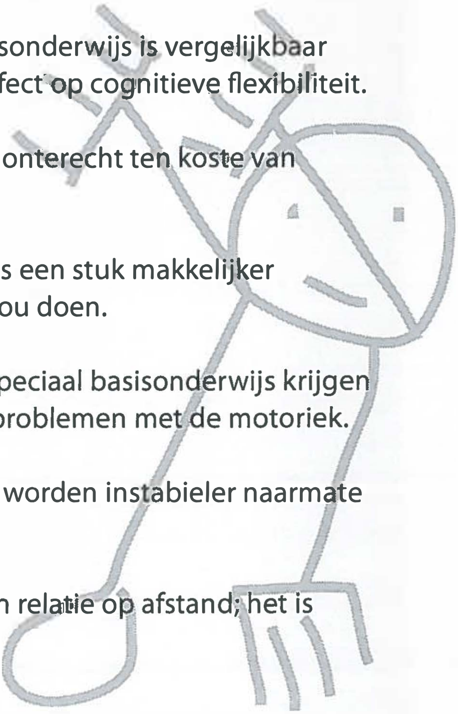
6. Bezuinigingen in het onderwijs gaan onterecht ten koste van de gymnastiekles (dit proefschrift).

7. Het verdedigen van een proefschrift is een stuk makkelijker wanneer men dat op een loopband zou doen.

8. Leerproblemen van kinderen in het speciaal basisonderwijs krijgen onevenredig meer aandacht dan de problemen met de motoriek.

9. De fundamenten van de wetenschap worden instabieler naarmate de druk tot presteren groter wordt.

10. Promoveren is als het hebben van een relatie op afstand; het is niet altijd even leuk.



Pieter Jelle Vuijk, 17 oktober 2012

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Contents

Chapter 1

General introduction

Background

In recent years a considerable body of research has been conducted on the relation between motor functioning and cognitive functioning over the lifespan (e.g. Voelcker-Rehage, Godde, & Staudinger, 2010; Wassenberg et al., 2005). Cognitive functioning can be considered an umbrella term for a variety of functions like the "standard" neuropsychological domains intelligence, attention, memory, and executive functioning, but also academic performance on reading, spelling, and mathematics can be considered as expressions of cognition. As far back as the classical Latin history people realized that a healthy body would lead to a sound mind or in Latin "Mens sane in corpore sano". Much later, Piaget (1952) reinvented the importance of adequate development of motor skills for the development of cognition in children. Children with good motor abilities have more opportunities to actively explore the world around them creating more opportunities to acquire experiences, which in turn will have a positive effect on their developing brain and thus the development of their cognitive functions.

The early neuroscientists were predominantly interested in the localization of (cognitive) functions in the brain. For example, motor skills were initially attributed to the cerebellum (Holmes, 1939), while executive functions, a subdomain of cognition, were solely attributed to the prefrontal cortex (Luria, 1966). Once neuroimaging methods slowly started to emerge in neuropsychological research, scientist started to realize that brain regions are interconnected and work together In the 90's scientists discovered that the prefrontal cortex becomes active when a subject is performing a motor task and when a subject is performing a cognitive task the cerebellum became active (e.g. Grasby et al., 1994; Raichle et al., 1994). These findings indicated that both the cerebellum and the prefrontal cortex are functionally connected or put it in other words; motor skills and cognition are interrelated.

Theoretical framework

Neurological imaging studies have found important connections between the cerebellum, a brain area important for motor skills, and the prefrontal cortex, an area important for cognition and academic skills. Neuropsychological research of children with developmental disabilities, for example ADHD (Martin, Piek, Baynam, Levy, & Hay, 2010), autism spectrum disorder (Behere, Shahani, Noggle, & Dean, 2012) and dyslexia (Iversen, Berg, Ellertsen, & Tonnessen, 2005), where the integrity of the brain is affected, showed that the prevalence of motor problems is higher in these groups compared to the population of typically developing children.

The current thesis examines if there is a relation between intelligence and motor problems by comparing groups of children with different levels of intellectual functioning and attending special education on their motor performance (i.e. manual dexterity, balance, and object control). Furthermore, the relation between motor performance and academic achievement (i.e. reading, spelling, and mathematics) is being examined. If a relation exists, than this study can contribute in an important way to the development of motor-based intervention programs in order to improve cognitive functioning and academic achievement.

Objectives and outline of this thesis

The goal of this thesis is to examine four groups of children between 6 and 12 years old that differ from each other in general cognitive ability. Three groups of children attend special education. One of those groups consisted of children with mild intellectual disability (MID), that is, children with an IQ between 50 and 70. Another group of children are children categorized as borderline intellectual functioning (BIF). These children have IQ-scores ranging from 71 through 84. The third group consists of children attending special education with a learning disability (LD). Children with learning disabilities are being described as children with below average intelligence or higher (IQ> 80) with problems acquiring academic skills in reading, spelling, and mathematics that cannot be attributed to their IQ. The fourth group consists of children attending regular education and IQ scores are assumed to be in the normal range.

Two different tests are used to examine motor development. The children attending special education are examined by using the Movement ABC (MABC; Henderson & Sugden, 1992) for children. The MABC is a frequently used test to determine quantitative motor problems in children on three important motor domains (i.e., manual dexterity, ball skills, and balance). For example, children performing below the 5th percentile on this test have definite motor problems.

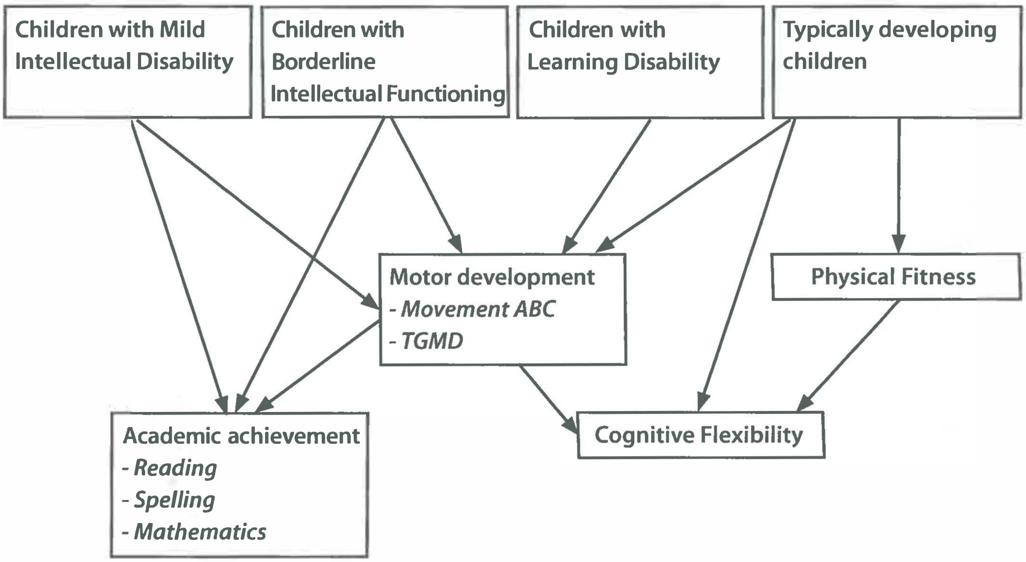

Figure 1.1 Schematic representation of the associations being examined in this thesis

Motor performance of children attending regular education is being examined with the Test for Gross Motor Development-second edition (TGMD-2; Ulrich, 2000) because they are expected to have a low incidence of motor problems. Because the TGMD is qualitative measure of motor performance (hereafter this will be named motor proficiency), the children in this research group will show enough variation in this variable to examine the relation with motor proficiency and cognition.

The academic achievement scores on reading, spelling, and mathematics are extracted from the personal files at school and are taken as measures of cognition for the three groups of children attending special education. The personal files also contain the IQ-scores since an assessment of cognitive functioning is a prerequisite for referring a child to special education. The group children attending regular education are being examined using the Trail Making Test (TMT; Reitan & Wolfson, 2004), a test used for measuring cognitive flexibility.

In the second chapter, the relation between intelligence and motor performance is examined by comparing a group of children with mild intellectual disability to a

group of children with borderline intellectual functioning using the Movement ABC as a quantitative measure of motor performance. Interestingly enough, motor functioning in these two groups, in particular children with mild intellectual disability, has not been researched extensively. If a relation between cognition and motor performance exists we expect to find differences in the prevalence of motor problems between these groups.
In the third chapter, the motor profile of a large group of children with learning disabilities is being examined. Furthermore, motor performance is being related to academic achievement. A considerable body of evidence has been gathered over the years on a variety of well-defined groups of children with a specific learning disability and its relation with motor functioning. It would be interesting to examine if the relation between motor functioning and specific learning disabilities can also be found in a heterogeneous and ecological valid group of children attending special needs schools. If such a relation can be found, it would strengthen the idea of a general theory of the high comorbidity rates between children with neurodevelopmental disorders and motor problems.

The fourth chapter will examine the relation between motor performance and academic achievement on reading, spelling, and mathematics in children with mild intellectual disability and borderline intellectual functioning. Children within these groups have academic achievement difficulties with all academic skills; i.e. reading, spelling, and mathematics, but are not considered learning disabled because their low IQ is thought to be responsible for their academic problems. It would be interesting if in these groups of cognitive low functioning children a relation between motor development and academic achievement can be found. If associations can be found in these two groups of cognitive low functioning children, a next step could be designing a motor-based intervention study in order to improve cognition in these children.

In the fifth chapter we examine typically developing children. Typically developing children have intelligence scores within the normal range and will attend regular education instead of special needs schools. We can assume that their brain development follows a normal trajectory. This chapter focuses on the relation between motor proficiency (the quality of movement) and cognitive flexibility (set-shifting) as a measure of cognition. Cognitive flexibility is the ability to adapt to behavior according to the context requirements and problems in this domain can lead to a wide variety of neuropsychiatric disorders such as learning disabilities and ADHD. We expect to find a positive relation between level of motor proficiency and cognitive flexibility.

The sixth chapter also examines the relation of motor proficiency on cognition in typically developing children but now in combination with physical fitness. Previous research has established a relation between motor performance and cognition (e.g. Diamond, 2000) as well as the relation between physical fitness and cognition (e.g. Etnier, Nowell, Landers, & Sibley, 2006), but the relations of motor performance and physical fitness simultaneously on cognition have not yet been examined. If both motor performance and physical fitness show significant associations with cognition then they each explain some unique variance in cognition. This would be an interesting finding for researchers developing an intervention program for children in order to improve cognition, as an intervention should not only focus on increasing motor skills but should also aim to improve physical fitness.

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Chapter 2

Motor performance of children with mild intellectual disability and borderline intellectual functioning

Pieter Jelle Vuijk | Esther Hartman | Erik J.A. Scherder | Chris Visscher

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Chapter 2

Motor performance of children with mild intellectual disability and borderline intellectual functioning

Abstract

Background: There is a relatively small body of research on the motor performance of children with mild intellectual disabilities and borderline intellectual functioning. Adequate levels of motor skills may contribute to lifelong enjoyment of physical activity, participation in sports and healthy lifestyles. The present study compares the motor skills of children with ID to the abilities observed in typically developing children. It also aimed to determine whether there is an association between degree of ID and motor performance.

Methods: A total of 170 children between 7 and 12 years old with mild intellectual disability or borderline intellectual functioning, who attended schools for special education, were examined on the test component of the Movement ABC Test. Both groups were compared with the norm scores of the total score, subscale scores, and individual items of the Movement ABC Test.

Results: 81.8% of the children with mild intellectual disability and 60.0% of the children with borderline intellectual functioning performed below the 16th percentile on the total score of the Movement ABC. Both groups demonstrated a relative weakness in the area of manual dexterity. Comparisons between both groups showed small to moderate effect sizes on the total score of the Movement ABC, as well as for all three subscales, favoring the children with borderline intellectual functioning.

Conclusions: Children with ID had significantly more borderline and definite motor problems than the normative sample and there was an association between degree of ID and performance of manual dexterity, ball skills, and balance skills. This study highlights the importance of improving motor skill performance in both children with borderline and mild ID, and the results support the notion that the level of motor and cognitive functioning are related in children with ID.

Introduction

The American Association on Intellectual and Developmental Disorders (AAIDD, formerly known as AAMR) defines intellectual disability (ID), formerly referred to as mental retardation, as 'Intellectual disability is characterized by significant limitations both in intellectual functioning and in adaptive behavior as expressed in conceptual, social, and practical adaptive skills. This disability originates before age 18.' (Schalock et al., 2007, p. 118). Pratt and Greydanus (2007) elaborated on this definition by stating that individuals with ID have limitations in developmental skills in several domains of functioning including cognitive, motor, auditory, language, psychosocial, moral judgment, and specific integrative adaptive activities of daily living. Even though deficits in motor functioning are mentioned above, there is surprisingly little research in this domain on individuals with ID, particularly children with ID. When considering that adequate levels of motor skills may contribute positively to activities of daily living (Watkinson et al., 2001), lifelong enjoyment of physical activity, participation in sports (Wall, 2004; Krombholz, 2006), and less sedentary behavior (Wrotniak et al., 2006), it is important that motor functioning in children with ID is examined.

Previous research has focused mostly on ID with a known etiology, such as Down's syndrome (i.e. Vicari, 2006), Williams syndrome (i.e. Tsai et al., 2008), and children with a more profound ID (i.e. Van der Putten et al., 2005), but not on children with a mild intellectual disability (MID), defined as children with an IQ score between 50 and 70 (American Psychiatric Association, 2000). This limited body of research is particularly striking considering that the estimations of the prevalence of MID is around 3.4% (Roeleveld et al., 1997).

Some early research, that focused on children with MID, showed delays in the development of motor skills (Francis & Rarick, 1959; Rarick, 1973; Bouffard, 1990). For example, children with MID appear to be 3 to 5 years behind in gross and fine motor skills in comparison with typical functioning children of the same age (Rarick, 1973). Hagberg (1981) found that 23% of the children in a group of Swedish school children with MID were identified with "clumsy child syndrome" (a former term for children with motor impairment; i.e. Sigmundsson, 2005). Savage (2007) examined a group of children with ID (IQ<70) on two motor tasks from the Dyslexia Screening Test (Fawcett & Nicolson, 1996). The first motor task was bead threading which was used as a measure of dynamic cerebellar functioning and the second task was postural stability which was used as a measure of static cerebellar functioning. The scores for children with ID were below the normative scores on bead threading but not on the postural stability task. The lack of effect in the second task may be attributed to the fact that the postural stability task is a qualitative measure of balance which may very well differentiate less compared to the more quantitative measure of fine motor skills found in bead threading. More recently, Wuang et al. (2008) examined a total of 233 children with MID aged 7 to 8 years on 22 measures of sensorimotor functioning. Around 44% of the children scored in the impaired range on 7 out of 22 measures.

The limited body of research on motor performance in children with MID also applies to children with borderline intellectual functioning (BIF), which includes children with an IQ between 71 and 84 (American Psychiatric Association, 2000). Children with BIF belong to a group which comprises up to 7% of the school age population (Karande et al., 2008), and although this is a significantly large group of children, there is similarly little research in this area (Ninivaggi, 2001; Kaznowski, 2004), and little research specifically on children with BIF and their motor functioning. Two studies addressed motor functioning in children with BIF (Hetrick, 1979; Karande et al., 2008). In the former study, children with BIF performed more poorly than their chronological aged typical functioning peers on the Bender visual-motor task (Koppitz, 1964). In the latter study, of a group of 55 children with BIF, 27.3 % had delays in walking, and 92.7% demonstrated difficulty with writing.

All the studies above compared a group of intellectually disabled individuals against the norms of the general population, a sample of individuals whose intellectual function is within normal limits or typically functioning individuals with an isolated learning disability. Considering the relatively small body of research on motor functioning of children with intellectual disability, we wanted to explore two new approaches. First, we compared two groups of children who are adjacent to each other in the spectrum of intellectual functioning, one with mild intellectual disability (MID) and the other with borderline intellectual functioning (BIF), with the norms of the general population. These groups with slightly different intellectual functioning children were compared on all the eight items of the Movement ABC thus creating a broad view of their status of motor development. Secondly, the groups were compared with each other in attempt to get an insight into potential differences in motor development between these two groups. In typically developing individuals a relationship between the acquisition of motor milestones and subsequent cognitive functioning at the ages 8, 26, and 53 has been observed (Murray et al., 2007). They suggested that the mechanism explaining their results was a suboptimal cortical-subcortical connectivity. Another study, by Reiss et al. (1996), also suggested a relationship between cognitive functioning and particular brain areas. Using a brain imaging study, they found that IQ was positively related with cerebral volume in children, in particular with cortical grey matter in the prefrontal region of the brain. Based on their results, we expected to find a difference in motor development between the MID and BIF group favoring the latter group. A possible difference in motor functioning between children with MID and BIF would suggest an extension of the atypical brain development (ABD) concept by Kaplan et al. (1998). ABD is a conceptual framework for understanding developmental learning disabilities and its high co-morbidity with other developmental disorders, such as developmental coordination disorder (DCD), PDD-NOS, and ADHD, by claiming that the etiology of developmental disorders is an atypical functioning of the brain. At this time, ID is not included in this framework. A lower degree of intellectual functioning would mean a higher degree of motor impairment. In order to examine these hypotheses we recruited children from two elementary schools for special education in order to obtain an ecologically valid sample with regard to variety in intelligence and co-morbidity.

Method

Participants

We recruited 190 children with ID from two elementary special needs schools in the northern regions of the Netherlands. Twenty children who were ill during the measurements or children without informed consent from their parents were excluded. The final study population included 170 children aged 7 to 12 (109 boys, 61 girls; mean age =10.0 yrs, SD=1.4 yrs) (Table 1). IQ-scores, extracted from the personal files of the children were used to classify the children in mild intellectual disability ($50 \leq IQ \leq 70$, n=55) and borderline intellectual functioning ($71 \leq IQ \leq 84$, n=115) according to the Diagnostic and Statistical Manual of Mental Disorder IV (DSM-IV-TR; American Psychiatric Association, 2000). Forty-four children across both groups were also diagnosed with PDD-NOS and 30 children with ADHD. Both groups did not statistically differ from each other on age, gender, % ADHD and % PDD-NOS. Informed consent for the children's participation was obtained from the parent(s) and all procedures were in accordance with the ethical standards of the Faculty of Medical Sciences of the University Medical Centre Groningen, University of Groningen.

Table 1. Characteristics of the children with mild intellectual disability (MID) and borderline intellectual functioning (BIF).

	MID (n=55)	BIF (n=115)	Test Statistic	
	Mean (SD)	Mean (SD)	t(168)	*p*-value
Age	9.93 (1.41)	10.06 (1.37)	.59	.56
IQ	65.27 (4.56)	77.38 (4.12)	17.32	<.001
	frequenties	frequenties	$x^2(1)$	
Gender (boys/girls)	35/20	74/41	.01	.93
ADHD (yes/no)	6/49	24/91	2.54	.11
PDD-NOS (yes/no	14/41	30/85	.01	.93

Note. ADHD, attention deficit hyperactivity disorder; IQ, intelligence quotient; PDD-NOS, pervasive development disorder - not otherwise specified

Materials

In order to assess motor performance, the test component of the Movement Assessment Battery for Children (MABC; 1st edition) was applied (Henderson & Sudgen, 1992). We used the MABC as it is a standard exam used worldwide for evaluation of children with movement difficulties (Smits-Engelsman et al., 1998; Smits-Engelsman et al., 2008). Smits-Engelsman et al. (1998) showed that the norms of the MABC are satisfactory for Dutch children. In this study, the Dutch validated version was used (Smits-Engelsman, 1998).

The MABC consists of four age-related item sets (4-6; 7-8; 9-10 and 11-12 years). Each age band consists of eight items, which are assessed under the following subscales: manual dexterity (3 items), balls skills (2 items), and static and dynamic balance (3 items). Some items are performed with the preferred hand as well as the non-preferred hand. Hand preference can be defined as the hand the child uses for writing (Henderson & Sudgen, 1992). Each item is scored on a scale from 0 to 5. Summing the item scores for every subtest provides a subscale score. The manual dexterity score varies from 0 to 15, the ball skill subtest score from 0 to 10, and the static and dynamic balance subtest score from 0 to 15. Subscale scores can be summed to give a total score for motor development ranging from 0 to 40. High scores indicate poor motor performance.

The total score on the MABC, as well as the subscale scores and item scores were converted into percentile scores that reflected the child's level of performance in comparison with children in the normative population. Children with a score between the 100th and 16th percentile were regarded as having 'no motor problems', 15th to 6th percentile as having 'borderline motor problems', and the 5th percentile and below as having 'definite motor problems'.

The MABC has acceptable validity and reliability in children from regular schools and schools for special education (Henderson & Hall, 1982; Lam & Henderson, 1987; Van Waelvelde et al., 2004). Inter-rater reliability ranges from .70 to .89 and the test-retest reliability is .75 (Henderson & Sudgen, 1992). The MABC has been used in a wide range of study populations, such as children with Down Syndrome (Spano et al., 1999), children with learning disabilities (Van Waelvelde et al., 2004), children born prematurely (Jongmans et al., 1997), deaf children (Gheysen et al., 2008), and children with visual impairments (Houwen et al., 2008).

Procedure

The items of the MABC were administered individually by master-students in Human Movement Science. The test leaders were thoroughly trained in the test prior to the data collection (training included familiarization with all procedures and scoring methods). MABC testing was carried out according to the manual of this test. Appropriate age bands were used for all children. Within the MID group 12 children completed the items of age band 2, 17 children the items of age band 3, and 26 children the items of age band 4. Within the BIF group, 16 children completed the items of age band 3, 52 children completed the items of age band 3, and 47 children completed the items of age band 4. There was no statistical difference in the distribution of the children over the 3 different age bands across groups ($X^2(2) = 3.64$; p=.16).

Data analysis

Data analysis was conducted using SPSS for Windows 15.0. The motor performance of the children was classified as 'no motor problems', 'borderline motor problems' (below the 15th percentile) or 'definite motor problems' (below the 5th percentile) in comparison with the percentage expected in a normal population. This was done for the total score and the subscales of the MABC as well as for the individual items. The distribution of the classifications in our sample was tested by use of a χ^2-test. For examining the difference on motor performance between the children with MID and children with BIF, the non-parametric Mann-Whitney U test was used. Correlational effect size statistics were calculated for each dependent variable by dividing the z-score by the square root of the sample size (Rosenthal, 1991). An effect size of $r = .10$ was defined as small, $r = .30$ as medium, and $r = .50$ as large (Field, 2005). For all analyses, a statistical significance level of .05 was used.

Results

Motor profile of children with MID on the total and subscale scores of the MABC

The χ^2-tests in Table 2 revealed that the proportion of children with MID with borderline or definite motor problems differed significantly from the normative population. It shows that 20.0% of the children with MID had borderline motor problems and 61.8% had definite motor problems as measured by the total score on the MABC. Examination of the subscales showed that 70.9% of the children had borderline or definite motor problems on the subscale manual dexterity and 63.6% of the children on the subscales ball skills and balance.

Motor profile of children with BIF on the total and subscale scores of the MABC

Children with BIF also had a motor profile that differed from the normative sample as indicated by the χ^2-tests in Table 2, with 17.4% of the children had borderline motor problems and 42.6% had definite motor problems as indicated by the total score on the MABC. Examination of the subscales showed that 56.5% of the children had borderline or definite motor problems on the subscale manual dexterity and 44.3% of the children on the subscales ball skills and balance.

Motor profile of children with MID on the item scores of the MABC

Within the subscale manual dexterity, the items 'speed and accuracy of each hand separately' and 'eye-hand coordination' showed more children with borderline or definite motor problems, respectively 72.7% and 67.3%, compared to 50.9% of the children on 'bimanual coordination' (Table 2). Within the subscale ball skills, 47.3% and 49.1% of the children had borderline or definite motor problems on the items 'catching a moving object' and 'aiming at a goal'.

Table 2. Motor profile of children with MID (n=55) and BIF (n=115) on the total score, the subscales, and the separate items of the MABC compared with the distribution of the normative sample.

		No motor problems (%)	Borderline motor problems (%)	Definite motor problems (%)	X^2 (2)	*p*-value
Total MABC	MID	18.2	20.0	61.8	389.50	<.001
	BIF	40.0	17.4	42.6	359.00	<.001
Manual dexterity	MID	29.1	18.2	52.7	274.48	<.001
	BIF	43.5	14.8	41.7	336.40	<.001
Speed and accuracy of	MID	27.3	47.3	25.5	144.00	<.001
each hand separately	BF	38.3	29.6	32.2	243.41	<.001
Bimanual	MID	49.1	16.4	34.5	106.59	<.001
coordination	BIF	73.0	9.6	17.4	37.27	<.001
Eye-hand	MID	32.7	23.6	43.6	192.11	<.001
coordination	BIF	42.6	24.3	33.0	228.87	<.001
Ball skills	MID	36.4	27.3	36.4	139.92	<.001
	BF	55.7	24.3	20.0	87.08	<.001
Catching a moving	MID	52.7	25.5	21.8	50.99	<.001
object	BIF	71.3	11.3	17.4	38.05	<.001
Aiming at a goal	MID	50.9	29.1	20.0	52.32	<.001
	BIF	64.3	22.6	13.0	38.93	<.001
Balance	MID	36.4	34.5	29.1	112.28	<.001
	BIF	55.7	20.9	23.5	103.77	<.001
Static balance	MID	27.3	45.5	27.3	145.27	<.001
	BIF	34.8	40.9	24.3	229.80	<.001
Dynamic balance	MID	30.9	34.5	34.5	148.09	<.001
while moving fast	BIF	43.5	32.2	24.3	165.97	<.001

to be continued on page 20

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Dynamic balance	MID	72.7	12.7	14.5	11.41	.003
while moving slowly	BIF	82.6	6.1	11.3	10.98	.004

MID = Mild Intellectual Disability, BIF = Borderline Intellectual Functioning, MABC = Movement Assessment Battery for Children

Finally, on the subscale static and dynamic balance, 72.7% and 69.1% of the children had borderline or definite motor problems on 'static balance' and 'dynamic balance (fast)' and 27.3% of the children on the item 'dynamic balance (slow)'.

Motor profile of children with BIF on the item scores of the MABC
Within the subscale manual dexterity, the items 'speed and accuracy of each hand separately' and 'eye-hand coordination' showed more children with borderline or definite motor problems, respectively 61.7% and 57.4%, compared to 27.0% of the children on 'bimanual coordination' (Table 2). On the items of the subscale ball skills 28.7% and 35.7% of the children demonstrated borderline or definite motor problems with 'catching a moving object' and 'aiming at a goal'.
Finally on the subscale static and dynamic balance, 65.2% and 56.5% of the children had borderline or definite motor problems on respectively 'static balance' and 'dynamic balance (fast)' and 17.4% of the children on the item 'dynamic balance (slow)'.

Comparisons between children with MID and BIF on total and subscale scores of MABC
Table 3 shows that children with MID scored significantly higher (i.e. more poorly) than children with BIF for the total score on the MABC (p=.003, r=.23), manual dexterity (p=.032, r=.16), ball skills (p=.015, r=.19), and balance (p=.024, r=.17). The effect size statistics indicated small-to-moderate effects.

Table 3. Comparisons of children with Mild Intellectual Disability (MID) and Borderline Intellectual Functioning (BIF) on the total and subscale scores of the Movement ABC.

	MID (n=55)				BIF(n=115)						
Total score and subscales	M	SD	Mdn	Range	M	SD	Mdn	Range	Z	P	*ES*
Total MABC	17.13	7.95	15	4-36.50	13.41	8.27	12	0-38	-2.96	.003	.23
Manual Dexterity	7.30	3.77	6.5	.50-15	5.94	3.81	5.50	0-14.50	-2.14	.032	.16
Ball Skills	3.68	2.94	3	0-10	2.63	2.81	2	0-10	-2.43	.015	.19
Balance	6.15	3.74	5.5	0-15	4.84	3.44	4	0-15	-2.26	.024	.17

Discussion

The present study consisted of two parts. First, we investigated the degree of motor impairment in children with MID and children with BIF (all attending schools for special education) compared to the normative population. Second, we searched for differences between children with MID and children with BIF on motor performance. The first part of the study showed that after combining the percentages of the children with borderline motor problems and definite motor problems, 81.8% of the children with MID have some degree of motor problems as compared to 60.0% of the children with BIF. These percentages are considerably higher than the 50% co-morbidity rates found between children with learning disabilities (LDs) and children with developmental coordination disorder (Lyytinen & Ahonen, 1989; Kaplan et al., 2001). In the Netherlands, children with LDs attend the same schools of special education as the children in our sample. This would suggest that schools for special education should recognize that their students are not all functioning at the same motor level and physical education classes may be modified to address each child at his own level of motor functioning.

Comparison of the subscales of the MABC showed that manual dexterity was relatively most difficult, with 70.9% of the children having borderline or definite motor problems in the MID group and 56.5 % in the BIF group. The subscales ball skills and balance showed relatively less motor impairment with 63.6% of the children in the MID group having borderline or definite motor problems on both subscales against 44.3% of the children in the BIF group. These results are in accordance with a study by Wuang et al., (2008), which revealed that children with MID had relatively more severe deficits with fine motor skills, comparable to the manual dexterity subscale of the MABC (Henderson & Sudgen, 1992), than with gross motor skills which are comparable to the subscales ball skills and balance of the MABC. This advantage of gross motor skills over fine motor skills was frequently found in other research groups (i.e. DCD and LD, Smits-Engelsman et al., 2003). Wuang and colleagues (2008) suggested that this is presumably caused by the fact that fine motor skills exert a greater demand on the maturity and integrity of the cortical nervous system, in particular the frontoparietal network (Davare et al., 2006). Within the manual dexterity subtest, the children demonstrated more deficiencies in 'speed and accuracy of each hand separately' and 'eye-hand coordination' than in 'bimanual coordination'. It seems that the children have more problems with accuracy of one hand than with items that require interlimb coordination. On the item bimanual coordination, the task is performed with the preferred hand, while the other hand is supportive. This may result in a relatively less cognitively demanding item than the other items of manual dexterity. The item 'speed and accuracy of each hand separately', for example, was also performed with the non-preferred hand, which appeared to be more difficult for children with ID. The findings are in agreement with those of Lahtinen et al. (2007) who found in adolescents and adults with ID that intelligence had a significant effect, favoring those with higher intelligence, on the test item 'pearl transfer speed' which resembled the item 'speed and accuracy of each hand separately'. The present study provides further evidence that people with ID are impaired on specific manual dexterity items to children with ID.

Motor performance on the subscale ball skills showed motor problems in 63.6% and 44.3% respectively in children with MID and BIF. Unfortunately, no other comparable studies with similar samples of children could be found for comparison of these results. To adequately execute these tasks, a child must not only rely on his eye-hand coordination (Binsted et al., 2001), but also has to plan his movement and force of throwing, particularly in reference to the item 'aiming at a goal'. We therefore argue that, based on animal and human studies, ball skills would rely more on cortico-subcortical systems. For example, in monkeys the striatum and its nigrostriatal afferents are involved in hand-eye coordination (Matsumoto et al., 1999) and the striato-nigro-striatal as well as the fronto-striatal circuits are involved in the planning of movements (Haber, 2003). The performance on the subscale balance was quite similar to the performance on ball skills with 63.6% and 44.3% respectively of children with MID and BIF having borderline or definite motor problems. Examination of the individual items of the subscale balance showed that the item 'dynamic balance while moving slowly' did not discriminate very well with 72.7% and 82.6% respectively of the children with MID and BIF having no motor problems. In contrast, the items 'static balance' and 'dynamic balance while moving fast' appeared to discriminate very well between the normal population and children with MID and BIF with respectively 72.7% and 65.2% of the children having borderline or definite motor problems on static balance and respectively 69.1% and 56.5% of the children having borderline or definite motor problems on dynamic balance while moving fast. These findings are in agreement with those of Lahtinen et al. (2007) who found impaired static balance (measured by the stork balance test) in adolescents and adults with ID. One can only speculate about the mechanisms underlying this finding. One such mechanism might be a suboptimal functioning of the vestibulocerebellum (Pritchard & Alloway, 2007).

The second part of our study, the comparison of two groups of children attending special education who differed in intellectual functioning, showed small to moderate effect sizes on motor performance as measured by the total score of the MABC as well as the three subscale scores. This could easily be explained by a brain imaging study by Reiss et al. (1996), who found that IQ is positively correlated with total cerebral volume in children and in particular with cortical grey matter in the prefrontal region of the brain. To a lesser extent, they found a positive correlation between IQ and subcortical grey matter.

The results discussed above would support the atypical brain development concept (Kaplan et al., 1998; Gilger & Kaplan, 2001), which is a conceptual framework for understanding developmental learning disabilities and its high co-morbidity with other developmental disorders like PDD-NOS, ADHD and DCD by claiming that the etiology of developmental disorders is due to atypical functioning of the brain, in multiple ways. First, children with ID have a higher co-morbidity rate of ADHD, with prevalence rates between 9% and 15% (Hastings et al., 2005), of autism spectrum disorders, with prevalence rates between 20% to 30% (Nordin & Gillberg, 1996; Towbin, 1997) and epilepsy with a prevalence rate of 12% in schoolchildren with mild ID (Hagberg et al., 1981). Second, the co-morbidity rate increases when the degree of intellectual impairment increases (i.e. Corbett et al., 1975; Beckung et al., 1997; Di Blasi et al., 2007). Third, as the present study shows, children in the MID group have a higher incidence of motor problems compared to the group of children with BIF who are adjacent to the continuum of general cognitive functioning. Fourth, MRI research on mild and severe ID with unexplained etiology concluded that people with mild or severe ID, in comparison with controls, had a higher incidence of brain anomalies, specifically in the periventricular white matter, lateral ventricular dilatation, mild corpus callosum abnormalities and subtle cerebellar abnormalities including fissure enlargement (Decobert et al., 2005). This would suggest that the concept of atypical brain development, which was originally developed for understanding the high co-morbidity between LD and diverse developmental disorders like ADHD and DCD, should be expanded to include children with intellectual disabilities (i.e., children with an IQ score below 85).

An association was found between degree of ID and motor performance. A limitation of this study, because of the cross-sectional nature of the study, is that the results give no insight into the causality of this association. It is unclear whether better motor performance leads to higher intelligence, or vice versa. Future longitudinal studies are needed to identify the direction of the associations that were found.

In conclusion, children with ID had significantly more borderline and definite motor problems than the normative sample and there was an association between degree of ID and performance of manual dexterity, ball skills, and balance skills. The study highlights the importance of improving motor skill performance in both children with borderline and mild ID, and the results support the notion that the level of motor and cognitive functioning are related in children with ID.

The results of the present study suggest that children with ID might benefit from a motor intervention that addresses their motor skills, especially those involving manual dexterity and static balance. The finding that the motor problems are most pronounced in the most intellectually challenged children supports the notion that special attention should be paid to this subgroup of children with ID.

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Chapter 3

Associations between the academic and motor performance in a heterogeneous sample of children with learning disabilities

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Chapter 3

Associations between the academic and motor performance in a heterogeneous sample of children with learning disabilities

Abstract

A heterogeneous sample of 137 school-aged children with learning disabilities (IQ>80) attending special needs schools was examined on the Movement Assessment Battery for Children (MABC). The results show that, compared to the available norm scores, 52.6% of the children tested performed below the 15th percentile on manual dexterity, 40.9% on ball skills, and 33.7% on balance skills. Furthermore, after controlling for IQ, significant small to moderate partial correlations were found between spelling and mathematics and the MABC total score, as well as small to moderate correlations between mathematics and balance, between reading and ball skills, and between spelling and manual dexterity. The present findings are compared with previously reported results obtained in more homogenous groups, and, based on the resultant relationships between academic performance and motor development, recommendations for future motor intervention studies are made.

Introduction

In the Netherlands 2.7% of all children attend special needs schools (CBS, 2010) with mostly heterogeneous populations. Teachers are hence confronted with children with a wide range of learning disabilities (LDs) often in combination with developmental disorders like attention-deficit hyperactivity disorder (ADHD), pervasive developmental disorder – not otherwise specified (PPD-NOS), and developmental coordination disorder (DCD).

Based on previous research of the associations between children with LDs and motor performance, LDs can roughly be divided into reading disorders, mathematical disorders, and developmental speech and language disorders. Studies using the Movement Assessment Battery for Children (MABC; Henderson & Sudgen, 1992) showed a positive relationship between poor reading and poor motor performance, i.e., children experiencing more reading difficulties also have a higher risk of motor problems (Cruddace & Riddell, 2006; McPhillips & Sheehy, 2004). Two studies (Barnhardt, Borsting, Deland, Pham, & Vu, 2005; Sortor & Kulp, 2003) found a similar positive association in children with poor mathematical achievements and their motor correlate, the Beery Developmental test of Visual Motor Integration (VMI; Beery, 1997). Finally, research on language impairments (Owen & McKinlay, 1997) and developmental speech and language disorders (Visscher, Houwen, Scherder, Moolenaar, & Hartman, 2007) also showed a clear relationship between the degree of language impairment and motor performance as measured with the MABC in that children that exhibited more problems in language development also experienced more problems with motor skills.

Two studies specifically investigating spelling and disorders (Korkman & Pesonen, 1994) and reading disorders (Kooistra, Crawford, Dewey, Cantell, & Kaplan, 2005) and motor performance in children with and without the co-morbid developmental disorder ADHD, showed that motor performance was more affected in the children that had a LD in combination with ADHD. In his review, Kraijer (2000) mentioned only one study that examined the relationship between gross motor skills and LDs in combination with a diagnosis of PDD-NOS. In contrast to the previous studies, this latter study found no evidence to suggest that children with PDD-NOS and a LD perform worse on motor tasks than their peers without co-morbidity.

Taken together, the findings discussed above show a clear relationship between LD and motor performance, a relationship that becomes stronger when the LD is accompanied by a co-morbid developmental disorder, which often is the case (e.g. Dewey,

Wilson, Crawford, & Kaplan, 2000; Dykman & Ackerman, 1991; Fawcett & Nicolson, 1995; Gillberg & Rasmussen, 1982; Kaplan, Dewey, Crawford, & Wilson, 2001; Piek, Dyck, Francis, & Conwell, 2007; Pliszka, Carlson, & Swanson, 1999).
What could be the neurological correlates of these high co-morbidities in children with movement problems? A recent review of the literature did not produce a general model explaining this high degree of co-morbity (Green & Baird, 2005). A cerebellar theory of dyslexia has been brought forward to explain the relationship between problems with reading and motor problems often observed in children with dyslexia (Ramus, Pidgeon & Frith, 2003). This theory implies that problems in automating new movement sequences, poor motor control and poor timing skills leading respectively to problems with reading, writing and organization. This theory, combined with the suggestion that a dysfunction of the cerebellum leads to problems in general cognitive functioning and specifically in executive functioning, because of important striatal pathways between the cerebellum and the prefrontal cortex (Diamond, 2000), would lead to a third theory; the executive functioning hypothesis. That is, motor skill problems are indicatory of a dysfunction of the cerebellum leading to problems in the prefrontal cortex and subsequent problems with general cognitive functioning. Despite all the theories mentioned above, no consensus exists on a general theory. Therefore it would be interesting to study the relationship between motor performance and academic performance in order to look for relationships within a heterogeneous sample. If a general theory would exist, a relationship between motor performance and LDs should be evident not only in a homogenous sample but also in a heterogeneous sample.

Most of the studies mentioned above focused on a specific LD with or without a comorbid condition, which renders the groups of children tested relatively homogenous and not representative of the children generally found in Dutch special education. Furthermore, most studies used a general measure of motor performance or one specific motor task. What is new and also the primary goal of the present study, is to assess the motor performance and determine a motor profile using the MABC in an ecologically valid and heterogeneous sample of children in special education in order to chart the relative strengths and weaknesses in their motor performance. Our second goal was to investigate whether the relationships between motor performance and specific LDs with or without a co-morbid developmental disorder described in previous studies would also emerge in our ecologically valid and heterogeneous sample using academic performance on reading, spelling, and mathematics as the variables rather than a formal diagnosis of LD.

Method

Participants

We recruited 137 children aged 7 to 12 years (98 boys, 39 girls; mean age=10.7 yrs, SD =1.3 yrs) with confirmed learning disabilities from two elementary special needs schools in the northern regions of the Netherlands. Children were included if they were healthy, i.e., not suffering from any physical illness or injury at the time of testing, and informed consent was obtained from their parent(s) or caregiver(s). All procedures were in accordance with the ethical standards of the Medical Faculty of the University of Groningen.

For each child we screened its personal school file containing the child's demographic data, a short medical history, as well as the so-called child academic monitoring system (CAMS). The CAMS is a record each elementary school in the Netherlands keeps and which provides an overview of each child's progress in academic skills by evaluating these skills twice a year. Based on the information provided in the personal files, the children's mean IQ was 90.2 (SD=7.7). IQ scores were measured by school psychologists a part of the intake procedure to get admitted to special education. Twenty-three children (16.8%) had been diagnosed with co-morbid ADHD and 19 children (13.9%) with PDD-NOS.

Starting from group 3 (age 7) the CAMS provides, among other details, the child's didactical age (DA), expressed as the months of formal education a child has received, with a full school year consisting of 10 didactical months (excl. two months summer vacation) and the entire elementary school period a total of 60 months. When a child stays back a grade, 10 months are added to its total DA, but when a child doubles the final grade (group 8), its total DA will remain 60 months. Accordingly, a child attending group 5 that has progressed without staying back and is tested early February will have a DA of 25 months based on 20 months in groups 3 and 4, and another 5 months (September to February) in group 5.

Furthermore, the CAMS states the child's didactical age equivalent (DAE). Each child is tested twice a year on reading, spelling, and mathematics. To assess its reading abilities, the Dutch AVI *(Analyse van Individualiseringsvormen* or Analysis of Individual Word Forms; Visser, van Laarhoven, & ter Beek, 1998) is used during which test the child is required to read out several short stories whose sentence structures and word complexity gradually increase in difficulty. To assess improvements in spelling skills the SVS (*Vorderingen in Spellingvaardigheid* or Improvements in Spelling skills; van den Bosch, Gillijns, Krom, &

Moelands, 1997), a pencil and paper task requiring the child to write down words of increasing complexity that are read out by the teacher, is used. Math skills are measured by the WIG (*Wereld in Getallen* or World in Numbers; Remery, 2001), a realistic test requiring children to solve mathematical problems taken from everyday life. Based on the results of mentioned tests the child's DAE is calculated for each of the three academic domains.

We subsequently calculated the learning lag (LL) per academic domain for each child using the following formula: LL = 1- (DAE/DA). A child with a LL of .28 on reading has not mastered 28% of the reading level it should normally have achieved given its didactical age.
The CAMS were not always complete or up to date, preventing us from extracting the LLs for all children. Data of children with incomplete files or dated scores were not used for subsequent analyses. Table 1 shows the means based on the available LLs: for 120 children the mean LL (SD) for reading was .50 (.21); the mean LL (SD) for spelling was .51 (.18) based on 106 children, and for math 122 children had a mean LL (SD) of .47 (.17).

Table 1. Demographic variables for the participating children with learning disabilities (n=137)

	Mean	SD	Range	Missing
Age (yrs)	10.70	1.30	7.6-12.9	
IQ	90.20	7.70	80-120	
LL Reading	.50	.21	.00-.93	20
LL Spelling	.51	.18	.00-.87	34
LL Mathematics	.47	.17	.00-.84	18
Gender (boys/girls%)	98(71.5%)/39(28.5%)			
ADHD (%)	n = 23 (16.8%)			
PDD-NOS (%)	n = 19 (13.9%)			

Note. LL = Learning Lag; ADHD = attention-deficit/hyperactivity disorder; PDD-NOS = pervasive developmental disorder-not otherwise specified.

Materials

In order to assess delays or deficits in fine and gross motor development we had the children perform the Movement Assessment Battery for Children (MABC; Henderson & Sudgen, 1992). The MABC consists of four age-specific item sets (age bands: 4-6, 7-8, 9-10, and 11-12 years) of which we used the last three sets. Each set comprises eight items subdivided in three subscales: manual dexterity (3 items), balls skills (2 items), and static and dynamic balance (3 items). Some exercises are performed with the preferred as well as with the non-preferred hand, with hand preference being defined as the hand the child uses for writing (Henderson & Sudgen, 1992). Per subtest each item is scored on a 6-point scale with 0 indicating exemplary and 5 extremely poor performance and the sum of the item scores providing the subtest score. The manual dexterity and the static and dynamic balance subtest scores thus range from 0 to 15 and the ball skill subtest score from 0 to 10.

When subscale scores are summed this yields a total score for motor development which can hence range from 0 to 40, with higher scores indicating poorer motor performance.

All MABC scores can be transformed into percentile scores reflecting the child's level of performance in comparison with its peers. The range between the 100th and 16th percentile is taken to indicate 'no motor problems', the 15th to 6th percentile as signifying 'borderline motor problems', and the 5th percentile and below denoting 'definite motor problems'.

The MABC had acceptable validity and reliability (Henderson & Hall, 1982; Lam & Henderson, 1987; van Waelvelde, de Weerdt, de Cock, & Smits-Engelsman, 2004). Inter-rater reliability ranges from .70 to .89 and the test-retest reliability is .75 (Henderson & Sudgen, 1992).

Procedure

The MABC was administered individually in the gyms at the children's schools by MSc students in Human Movement Science who had received a formal training and testing was carried out in accordance with the MABC manual (Henderson & Sudgen, 1992).

Data analysis

Data analysis was conducted using SPSS for Windows 15.0. The children's motor performance in terms of the MABC item , subtest, and total scores was classified as 'no motor problems', 'borderline motor problems' (below the 15th percentile) or 'definite motor problems' (below the 5th percentile) in comparison to the percentage expected in a normal population. The classification was tested by use of a χ^2-test. Partial correlations were used to relate the MABC total score and its subscale scores to the learning lags (LLs) in reading, spelling, and mathematics after controlling for IQ. Correlations of .1, .3, and .5 were taken as indicating small, medium, and large effect sizes, respectively (Cohen, 1988). A statistical significance level of .05 was used for all analyses.

Results

Motor profile

Table 2 shows the MABC total and subscale scores in percentages for our LD sample. The χ^2-tests with the MABC total scores revealed that the proportion of children with motor problems in special education is significantly higher than found in the norm population attending mainstream elementary schools: 15.4% of our LD children had borderline problems and 35.0% definite motor problems.

With regard to the MABC subscales, manual dexterity had the highest percentage of children (52.6%) performing below the 15th percentile, while the static and dynamic balance subscale showed relatively better results with 33.6% of the children scoring below the 15th percentile.

Table 2. The total and subtest scores on the Movement ABC in percentages for all children (n= 137) and comparison with the normative sample

	No motor problems (%)	Borderline motor problems (%)	Definite motor problems (%)	χ^2	p-value
MABC Total score	49.6	15.4	35.0	271.25	<.001
Manual dexterity	47.4	14.6	38.0	323.22	<.001
Ball Skills	59.1	24.8	16.1	74.38	<.001
Balance	66.4	21.9	11.7	37.18	<.001

The χ^2-tests for the separate items (see Table 3) also revealed significant differences between our special needs children and their unaffected peers. As to manual dexterity, with 23.4% of the LD children showing borderline or definite motor problems, the test item 'bimanual coordination' yielded the lowest percentage of children performing below the 15th percentile. For the ball skills subscale, 'catching a moving object' was performed relatively well with only 24.1% of the children showing borderline of definite motor problems compared to the 32.1% for 'aiming at a goal'.

Table 3. Comparative outcomes (in percentages) for the separate Movement ABC items for the study (n= 137) and normative sample

	No motor problems (%)	Borderline motor problems (%)	Definite motor problems (%)	χ^2	p-value
Manual dexterity					
Speed and accuracy for each hand separately	46.7	24.1	29.2	211.24	<.001
Bimanual coordination	76.6	9.5	13.9	22.71	<.001
Eye-hand coordination	46.7	19.7	33.6	260.29	<.001
Ball skills					
Catching a moving object	75.9	14.6	9.5	9.75	.008
Aiming at a goal	67.9	20.4	11.7	31.87	<.001
Balance					
Static balance	52.6	32.8	14.6	113.72	<.001
Dynamic balance while moving fast	51.1	32.8	16.1	123.55	<.001
Dynamic balance while moving slowly	88.3	4.4	7.3	5.95	.051

Looking at balancing skills, we found that the LD group did not differ significantly (p=.051) from the norm population on the 'dynamic balance while moving slowly' exercise, with only 11.7% of the children showing borderline or definite motor problems. On the two other balance tests, however, 47.4% and 48.9% of our children showed borderline or definite motor problems.

Associations between academic and motor performance

When we correlated (Table 4) the children's reading, spelling, and math achievements with their MABC scores, this yielded significant effects for spelling and math for the total score. Moreover, the manual dexterity subscale yielded a significant correlation with spelling, the ball skills subscale with reading, and the balance subscale with math. All significant partial correlations were small to moderate.

Table 4. Partial correlations between the Movement ABC subtest outcomes and lags in learning (LLs) after controlling for total IQ

	Reading (n=117)	Spelling (n=103)	Mathematics (n=119)
Total MABC	.17	.22*	.19*
Manual Dexterity	.13	.23*	.13
Ball Skills	.18*	.09	.08
Balance	.08	.18	.22*

*p<.05. Two-tailed significance

Discussion

In our sample of 137 children with learning disabilities attending special needs schools the learning lag on reading, spelling and mathematics was around .50, signifying that, on average, the children did not master around 50% of the academic skills expected given their didactical age. Our investigations further showed that, apart from these learning deficits, their overall motor performance was quantitatively impaired, with 50.4% of the children performing below the 15th percentile on the MABC (total score). This percentage is almost identical to the co-morbidity rates reported for DCD and LD in previous studies (Kaplan, Wilson, Dewey, & Crawford, 1998; Lyytinen & Ahonen, 1989; Silva, McGee, & Williams, 1982).

When examining the MABC subtest scores more closely, we found the LD children to have the most problems with manual dexterity where 52.6% had below average motor skills, with 38.0% exhibiting definite motor problems. The performance of the exercises in this subtest involves fine motor skills (Henderson & Sudgen, 1992) and also draws on attention (Flapper, Houwen, & Schoemaker, 2006) and planning (van Gemmert & Teulings, 2006). Smits-Engelsman, Wilson, Westenberg, and Duysens (2003) found that children with DCD and LD also experienced problems performing a fine motor task and suggested the underlying cause to be a deficit in open-loop control as these children rely more on feedback during movement execution and have difficulty adopting a feed-forward or open-loop strategy. Consequently, they may have problems in planning and developing or applying strategies, which suggests an atypical functioning of the frontal lobe (Gouveia, Brucki, Malheiros, & Bueno, 2007).

The same holds for the ball skills subscale, where 40.9% of our LD children showed borderline or definite motor problems. In these exercises, children have to aim at a goal and catch a moving object. For their execution, a child does not only need to rely on its eye-hand coordination (Binsted, Chua, Helsen, & Elliott, 2001), but also, especially with respect to the 'aiming at a goal' exercise, needs to plan the progression and force of the throw ahead of the actual movement. As to the mechanism underlying this finding, we speculatively argue that the LD children in our sample may have had difficulty in performing these specific tasks due to a deficit in the ventral basal ganglia and interconnected midbrain nuclei, which are part of the corticobasal thalamocortical networks (Boecker, Jankowski, Ditter, & Scheef, 2008).

The MABC balance subtest was performed relatively best, with 33.6% of the children having borderline or definite motor problems. Closer examination of the three separate exercises, however, yielded a quite different picture. 'Static balance' and 'dynamic balance while moving fast' were definitely the most difficult, with 47.4% and 48.9% of the children having borderline or definite motor problems, respectively. However, the fact that on the total subtest only a third of the children performed below the 15th percentile was almost entirely attributable to the 'dynamic balance while moving slow' item, the performance of which fell within the normal range for 88.3% of the children. Apparently this task does not discriminate very well between affected and unaffected children.

Although previous studies found significant relationships between poor LD-related academic performance and poor motor performance (reading: McPhillips & Sheehy, 2004; Cruddace & Riddell, 2006; mathematics: Sortor & Kulp, 2003; Barnhardt, Borsting, Deland, Pham, & Vu, 2005), most samples were rather homogeneous and all studies relied on overall motor performance scores. We, therefore, looked at a more heterogeneous group and, besides three measures of academic performance and overall motor performance, also studied three subdomains of motor skills. After controlling for IQ levels, we found small to moderate correlations between the MABC total score and spelling, and math but not reading, implying that the children that had better motor skills had relatively smaller learning lags for spelling and math. But even more interesting were the significant relationships between the MABC subscales and the various academic parameters. We found a moderate correlation between manual dexterity and spelling, which association may be explained by the fact that spelling is tested by means of a paper and pencil task, which thus also draws on fine motor skills (Flapper, Houwen, & Schoemaker, 2006; van Gemmert & Teulings, 2006).

Finally, reading ability and ball skills were related in our study, which is in contrast to what Iversen, Berg, Ellertsen, and Tønnessen (2005) reported, comparing the MABC performance of dyslectic children, poor readers, and a control group of proficient readers. They found the dyslectics and poor readers to perform significantly worse on both manual dexterity and balance, but not on ball skills. That the latter outcome did not reach significance in this earlier study may be due to the small sample sizes.

It needs to be noted that research relying partially on existing, external data sources is inherently flawed to some extent. In our case the IQ data we used occasionally was more than two years old and obtained with different IQ tests. However, previous research to the stability of IQ scores showed that IQ total scores of children remain stable over time (i.e. Mortensen, Andresen, Kruuse, Sanders, & Reinisch, 2003; Livingston, Jennings, Reynolds, & Gray, 2003), so we think it is acceptable to use the information from the personal files. Moreover, due to incomplete school files, the information regarding academic progress was not available for all 137 children, but we could still include between 103 and 117 children with a recent (not older than 2 months) academic achievement score in the second part of our study. Despite these shortcomings, we feel that our results lend themselves well for generalization.

Our cohort of children experienced problems in a wide variety of areas; they (frequently) had a lowered IQ, learning disabilities in one or more academic skills, co-morbid psychopathology, and problems in many motor skills. These deficits all have a neurological origin. The high co-morbidity rates in our sample would justify the atypical brain development framework Gilger and Kaplan (2001) proposed, which they formulated founded on the growing awareness that developmental disabilities are typically nonspecific and heterogeneous. We find it quite interesting in this respect that the associations between motor performance and specific LDs reported in previous research of more homogenous study groups were also apparent in our heterogeneous sample. This finding would suggest that at least in a part a general theory explaining the high co-morbidities in children with movement problems does exist. As we do not have brain imaging results from these children, we can only speculate that the here observed associations might partly be caused by a dysfunction of the frontal cortex affecting executive functioning. Furthermore, the small to moderate partial correlations we obtained between the various aspects of motor performance and academic performance could suggest a causal relationship as Ridler et al. (2006) earlier suggested, finding that early motor development in infancy predicted superior executive functioning in adulthood. Future research should decide whether children that have been identified at a young age as being at risk of developing learning disabilities could benefit from a timely and targeted motor intervention.

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Chapter 4

Associations between motor development and academic achievement in a sample of children with mild intellectual disability or borderline intellectual functioning.

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Submitted

Associations between motor development and academic achievement in a sample of children with mild intellectual disability or borderline intellectual functioning.

Abstract

Previous research has found associations between motor functioning and academic achievement in children with various neurodevelopmental disorders. In children with intellectual disabilities this association has not yet been established. One hundred and seventy children in the age range 7 to 12 years old with mild intellectual disability (MID) or borderline intellectual functioning (BIF) were examined on motor performance with the Movement ABC. Motor performance scores on manual dexterity, ball skills, and balance were used to predict academic achievement on reading, writing, and mathematics using ANCOVA's controlling for age and group (i.e. MID and BIF). None of the motor domains showed significant associations with reading and spelling, in contrast, manual dexterity, ball skills, and balance all showed significant relations with mathematics with moderate effect sizes. We hypothesize that differences in cortical contributions to math and subcortical contributions to reading and spelling in children with a lowered IQ is at the foundation of the found correlations between motor performance and mathematics in our sample.

Introduction

Children attending special needs schools have a variety of developmental disabilities, including impaired IQ (Vuijk, Hartman, Scherder, & Visscher, 2010), problems with academic skills like reading, spelling, and mathematics (Sabornie, Cullinan, Osborne, & Brock, 2005; Vuijk, Hartman, Mombarg, Scherder, & Visscher, 2011; Wise, Sevcik, Romski, & Morris, 2010) and motor disabilities (Savage, 2007; Vuijk et al., 2010; Westendorp, Houwen, Hartman, & Visscher, 2011; Wuang, Wang, Huang, & Su, 2009).

Previous research investigating the relationship between motor performance and academic achievement mainly focused on populations of typically developing children attending regular education or children with a specific learning disorder (LD). For example, Skubic & Anderson (1970), were one of the first to study the interrelationship between perceptual-motor performance, academic achievement and intelligence in a group of 86 children with average intelligence. The researchers found an association between academically high and low achievers on 6 of 11 measures of perceptual-motor skills. These results should however be cautiously interpreted because of a lack of correction for multiple comparisons. In a later study, Kulp (1999) found significant relationships, of moderate size, between visual-motor integration skill (VMI; Beery, 1997) scores and academic skills (reading, writing, and spelling) in a group of one hundred and ninety-one children in the ages 7-9 attending regular schools. The VMI is however not a "pure" measure of motor functioning, but it appeals to motor coordination and visual perception. Two studies (Cruddace & Riddell, 2006; McPhillips & Sheehy, 2004) that examined the relation between poor motor performance measured with the movement assessment battery for children (MABC; Henderson & Sugden, 1992) and reading difficulties found a positive relationship, that is, children with reading difficulties had a higher risk of having motor problems.
As far as we know, only one study (Vuijk et al., 2011) examined the relationship between all three domains of the MABC, consisting of manual dexterity, ball skills, and balance, and three different measures of academic achievement (i.e. reading, spelling, and mathematics) in a group of children attending special education, but with IQ-scores above 80. In this study small to moderate partial correlations were found between ball skills and reading, manual dexterity and spelling, and balance and mathematics. It is suggested that the found relationships between these motor functions and academic achievements measures reflect a dysfunction of the cerebellum; a dysfunction of the cerebellum may affect the important striatal pathways between the cerebellum and the prefrontal cortex, causing general cognitive problems, specifically executive

dysfunctioning (Diamond, 2000; Vuijk et al., 2011). Based on the known close relationship between motor and cognitive functioning (Diamond, 2000), the clinical relevance of these findings is that an improvement in motor functioning could very well improve cognitive functioning.
A limitation of the studies mentioned above is that they all have in common that the children in the samples have IQ-scores of at least 80. In order to get a diagnosis LD most studies use an IQ score of 80 as a cut-off score which is in accordance with the definition of learning disabilities of the American Psychiatric Association (American Psychiatric Association, 2000).

Children with borderline intellectual functioning, having IQ scores between 71 and 84 (BIF; American Psychiatric Association, 2000) and children with mild intellectual disability, with IQ scores between 50 and 70 (MID; American Psychiatric Association, 2000) have more often than typically developing children motor problems. For example, Karande and colleagues (2008) found in a group of 55 children with BIF that 27.3% showed delays in walking and 92.7% demonstrated difficulty in writing. Another study showed that 81.8% of the children with MID and 60.0% of the children with BIF showed definite or borderline motor problems (i.e. performed below the 15th percentile) as measured with the total score of the MABC (Vuijk et al., 2010). Looking at the domain scores, manual dexterity appeared to be the most impaired motor domain in children with BIF as well as children with MID with respectively 56.5% and 70.9% of the children performing below the 15th percentile.
In this particular group of children, i.e. children with BIF and MID, the relationship between motor development and academic achievement has to our knowledge never been examined. Therefore, the objective of the present study was to examine the relationship between motor development and academic achievement in reading, writing, and mathematics in a sample of children with intellectual disability or borderline intellectual functioning attending special needs schools. We argue that if such a relationship exists, children with MID and BIF could benefit from a motor-based training program in order to improve academic achievement.

Method

Participants

We recruited 190 children with ID from two elementary special needs schools in the northern regions of the Netherlands. Twenty children, who were ill during the measurements or did not have an informed consent from their parents, were excluded. The final study population included 170 children aged 7 to 12 years (109 boys, 61 girls; mean age = 10.5 years, SD = 1.4 years).

For each child we screened its personal school file containing the child's demographic data, a short medical history, as well as the so-called child academic monitoring system (CAMS). The CAMS is a record each elementary school in the Netherlands keeps and which provides an overview of each child's progress in academic skills by evaluating these skills twice a year.

Starting from group 3 (age 7) the CAMS provides, among other details, the child's didactical age (DA), expressed as the months of formal education a child has received, with a full school year consisting of 10 didactical months (excl. two months summer vacation) and the entire elementary school period a total of 60 months. When a child stays back a grade, 10 months are added to its total DA, but when a child doubles the final grade (group 8), its total DA will remain 60 months. Accordingly, a child attending group 5 that has progressed without staying back and is tested early February will have a DA of 25 months based on 20 months in groups 3 and 4, and another 5 months (September to February) in group 5.

Furthermore, the CAMS states the child's didactical age equivalent (DAE). Each child is tested twice a year on reading, spelling, and mathematics. To assess its reading abilities, the Dutch AVI (*Analyse van Individualiseringsvormen* or Analysis of Individual Word Forms; Visser, Van Laarhoven, & Ter Beek, 1998) is used during which test the child is required to read out several short stories whose sentence structures and word complexity gradually increase in difficulty. To assess improvements in spelling skills the SVS (*Vorderingen in Spellingvaardigheid* or Improvements in Spelling skills; van den Bosch, Gillijns, Krom, & Moelands, 1997), a pencil and paper task requiring the child to write down words of increasing complexity that are read out by the teacher, is used. Math skills are measured by the WIG (*Wereld in Getallen* or World in Numbers; Remery, 2001), a realistic test requiring children to solve mathematical problems taken from everyday life. Based on the results of mentioned tests the child's DAE is calculated for each of the three academic domains.

We subsequently calculated the learning lag (LL) per academic domain for each child using the following formula: LL = 1- (DAE/DA). A child with a LL of .28 on reading has not mastered 28% of the reading level it should normally have achieved given its didactical age.

The CAMS were not always complete or up to date, preventing us from extracting the LLs for all children. Data of children with incomplete files or dated scores were not used for subsequent analyses. Table 1 shows the means based on the available LLs: for 145 children the mean LL (SD) for reading was .48 (.23); the mean LL (SD) for spelling was .52 (.19) based on 106 children, and for math 138 children had a mean LL (SD) of .55 (.17).

Finally, the IQ-scores extracted from the personal files of the children that were measured by school psychologists as part of the intake procedure to get admitted to special education, were used to classify the children in mild intellectual disability ($50 \leq IQ \leq 70$, n=56) and borderline intellectual functioning ($71 \leq IQ \leq 84$, n=116) according to the Diagnostic and Statistical Manual of Mental Disorder IV Text Revision (American Psychiatric Association, 2000).

All procedures were in accordance with the ethical standards of the Medical Faculty of the University of Groningen.

Materials

In order to assess delays or deficits in fine and gross motor development we had the children perform the Dutch version of the Movement Assessment Battery for Children (MABC; Henderson & Sugden, 1992; Smits-Engelsman, 1998). The MABC consists of four age-specific item sets (age bands: 4-6, 7-8, 9-10, and 11-12 years) of which we used the last three sets. Each set comprises eight items subdivided in three subscales: manual dexterity (3 items), balls skills (2 items), and static and dynamic balance (3 items). Some exercises are performed with the preferred as well as with the non-preferred hand, with hand preference being defined as the hand the child uses for writing (Henderson & Sugden, 1992). Per subtest each item is scored on a 6-point scale with 0 indicating exemplary and 5 indicating extremely poor performance. The sum of the item scores provides the subtest score. The manual dexterity and the static and dynamic balance subtest scores thus range from 0 to 15 and the ball skill subtest score from 0 to 10.

When subscale scores are summed this yields a total score for motor development which can range from 0 to 40, with higher scores indicating poorer motor performance.

All MABC scores can be transformed into percentile scores reflecting the child's level of performance in comparison with its peers. The range between the 100th and 16th

percentile is taken to indicate 'no motor problems', the 15th to 6th percentile as signifying 'borderline motor problems', and the 5th percentile and below denoting 'definite motor problems'.
The MABC had acceptable validity and reliability (Henderson & Hall, 1982; Lam & Henderson, 1987; Van Waelvelde, De Weerdt, De Cock, & Smits-Engelsman, 2004). Interrater reliability ranges from .70 to .89 and the test-retest reliability is .75 (Henderson & Sugden, 1992).

Procedure

The MABC was administered individually by MSc students in Human Movement Science who had received a formal training and testing was carried out in accordance with the MABC manual (Henderson & Sugden, 1992; Smits-Engelsman, 1998).

Data analysis

Data analysis was conducted using SPSS for Windows 15.0. Two-way ANCOVA's were used with academic achievement as the dependent variable and intellectual disability group as a factor with 2 levels (MID versus BIF), motor performance as a factor with 3 levels (definite motor problems, borderline motor problems, and no motor problems), and age as a covariate. Because both academic achievement (i.e. reading, spelling, and mathematics) and motor performance (i.e. manual dexterity, ball skills, and balance) consist of three separate domains, we conducted nine separate analyses. For each analysis a stepwise approach was used to estimate a final model per combination of motor domain and academic achievement domain. Non-significant interaction effects are dropped from the model. We applied a Bonferroni correction per academic achievement, so a significance level of .017 was used for all analyses. Eta squared effect sizes were calculated and effect sizes of .01, .06, and .14 were taken as indicating small, medium, and large effect sizes, respectively (Cohen, 1988).

Results

Table 1. shows that the proportion boys and girls in the two Intellectual Disability groups did not significantly differ from each other ($x^2(1) = .01$, $p=.93$). There were no significant gender differences on the academic achievement domains with the exception for spelling, where boys had a greater learning lag compared to girls ($t(104)=2.36$, $p=.02$).

Table 1. Mean age and learning lags for reading, spelling, and mathematics for the total group and for boys and girls separately (n=170)

		Total		Boys (n=109)		Girls (n=61)				
		Mean	SD	Mean	SD	Mean	SD	t-test	p-value	missing
Age (yrs)		10.5	1.4	10.4	1.4	10.6	1.3	-.83	.41	-
LL Reading		.48	.23	.51	.22	.43	.24	1.87	.06	25
LL Spelling		.52	.19	.55	.18	.46	.21	2.36	.02	64
LL Math		.55	.17	.54	.17	.56	.17	-.63	.53	32
		N(%)		N		N		$X^2(1)$	p-value	
Intellectual	MID	55(32.4%)		35		20		.01	.93	-
functioning	BIF	115(67.6%)		74		41				-

Note. LL = Learning Lag, MID = Mild Intellectual Disability, BIF = Borderline Intellectual Functioning

In Table 2. the results of the nine two-way ANCOVA analyses are presented. None of the models with the dependent variables reading and spelling rendered significant relationships with any of the independent variables in the analysis. The first model with mathematics as the dependent variable resulted, besides two significant main effects for manual dexterity and age, also in a significant interaction effect between manual dexterity and age. The interaction effect was an indication that no relationship between age and mathematics existed in the no motor problems group while the relationship between age and mathematics in the definite motor problems group was strong.

Table 2. Separate ANCOVA's for each combination of Academic Performance and Motor Domain.

Model	Reading			Spelling			Math		
	F-value	P-value	ES	F-value	P-value	ES	F-value	P-value	ES
ID group	.06	.81	.00	.50	.48	.01	3.36	.07	.02
Age	.25	.62	.00	.08	.78	.00	13.80	<.001	.10
Manual Dexterity	1.01	.37	.01	.03	.97	.00	6.43	.002	.08
*Manual Dexterity*Age*	-	-	-	-	-	-	5.77	.004	.07
ID group	.10	.76	.00	.41	.52	.00	2.40	.12	.02
Age	.30	.59	.00	.01	.88	.00	10.77	.001	.08
Ball Skills	.92	.40	.01	.53	.59	.01	5.71	.004	.08
ID group	.06	.81	.00	.57	.45	.01	3.40	.07	.03
Age	.09	.77	.00	.08	.79	.00	8.06	.005	.05
Balance	.38	.64	.01	.29	.75	.01	4.68	.01	.07

The ANCOVA with ball skills as the independent variable resulted in a moderate effect for ball skills while controlling for age. More problems with ball skills results in a larger learning lag on mathematics. The independent variable ID group was not significant. Finally, the ANCOVA with balance as the independent variable also resulted in a moderate effect for balance with more motor problems indicative for a bigger learning lack on mathematics while controlling for age.

Discussion

The current study examined the relationship between motor development and academic achievement in a group of children with mild intellectual disability (MID) or borderline intellectual functioning (BIF) attending special needs schools. The prevalence of borderline or definite motor problems in this sample is 81.8% for children with MID and 60.0% for children in the BIF group (Vuijk et al., 2010). Both groups have considerable deficiencies in their academic achievement in reading, spelling, and mathematics with children, on average, not mastering between 48% and 55% (see Table 1) of the aforementioned skills compared to their typically developing peers. Academic achievement difficulties in children with MID and BIF is more often the rule than the exception (Krishnakumar, Geeta, & Palat, 2006; Van der Molen, Van Luit, Van der Molen, Klugkist, & Jongmans, 2010).

With respect to gender, our initial results over the combined sample of children with MID and BIF show no significant differences on mathematics, which is in accordance with a recent world wide meta-analysis including typically developing children (Else-Quest, Hyde, & Linn, 2010). A trend for reading was found favoring girls, as well as a significant effect for spelling where girls had a smaller learning lag than boys. Of note is that previous research on gender differences in academic achievement also showed significant gender effects for reading in a large population based cohort (Katusic, Colligan, Barbaresi, Schaid, & Jacobsen, 2001) and spelling in a group of children diagnosed with ADHD (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008) favoring girls.
Our main objective was to examine possible relationships between motor performance and academic achievement. The results show a specific pattern. No significant effects were found between any of the motor domains and reading while controlling for intellectual disability. These results cannot be compared with similar studies examining children within the IQ range of 50 – 85, as these studies are lacking so far. A study examining children with LD did find a positive relationship between ball skills and reading but not with manual dexterity and balance and reading (Vuijk et al., 2011). Another study examining differences in motor performance between a group of children with dyslexia, poor readers, and controls found that children with dyslexia and poor readers performed worse on manual dexterity and balance but not on ball skills (Iversen, Berg, Ellertsen, & Tonnessen, 2005).
As for reading, we also did not found any significant relationships between the three measures of motor performance and spelling. Previous research in children born preterm found a higher incidence of academic problems in spelling when these children also met the criteria of developmental coordination disorder (DCD) compared to preterm children without a diagnosis DCD and a typically developing group of controls. Again, the selection criterion for the children in that study was an IQ of 80 or higher.
The present study did find moderate relations between all measures of motor performance and mathematics while controlling for age and intellectual disability group. Similar findings have been reported in a few other studies. For example, a significant relation between fine motor skills and mathematics has been found in a large sample of typically developing kindergartners and first graders (Luo, Jose, Huntsinger, & Pigott, 2007). A study examining the relationship between balance and mathematics found a significant relationship in a sample of 122 typically developing children between 7 and 11 years old (Knight & Rizzuto, 1993). Finally a study on the relationship of visual-motor coordination and mathematical achievement in a group of 44 elementary school children of which 15 children were learning disabled, 21 children had borderline intel-

ligence and 8 children had an IQ below 70, found a moderate effect. This effect disappeared however when the authors controlled for IQ (Goldstein & Britt, 1994). In our study, even though we controlled for intellectual disability we still found a moderate effect for ball skills on mathematics.

In an attempt to explain the presence of significant relationships between motor performance and mathematics and an absence of motor performance and reading and spelling in a group of children with intellectual disability we would like to present the following argument.

A linear relationship between IQ, assessed by the Wechsler Intelligence Scale for Children and cortical current density, measured by EEG, has been found (Thatcher, North, & Biver, 2007), implying that the stronger the neuronal synchronicity, the higher the IQ. More specifically, grey matter volume in the lateral prefrontal cortex is positively correlated with IQ (Shaw, 2007). In children with Williams syndrome, a developmental disorder characterized by mental retardation, motor problems, weaknesses in visuospatial processing, and serious impairments in mathematics (Hocking, Bradshaw, & Rinehart, 2008; O'Hearn & Luna, 2009), impairments in the fronto-parietal network is assumed to be the underlying cause of these problems. In premature children with extremely low body weight (Downie, Jakobson, Frisk, & Ushycky, 2003) and in patients with a left hemisphere ischemic stroke (Cloutman et al., 2009), subcortical white matter appeared to be important for reading and spelling. We hypothesize that it is this difference in cortical contributions to math and subcortical contributions to reading and spelling in children with a lowered IQ is at the foundation of the found relations between motor performance and mathematics in our sample.

The clinical relevance of our finding is supported by a recent motor intervention study from Sweden (Ericsson, 2008). A motor intervention program was designed in order to improve academic functioning in reading, spelling, and mathematics in a group of typically developing children. Her results indicated that children showed significant improvements on mathematic achievement but not on reading and spelling. Based on these results, future research should determine if a motor intervention program developed for children attending special education could have beneficial effects on their academic achievement.

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Chapter 5

Motor proficiency and cognitive flexibility in 6- to 12- year- old children

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Chapter 5

Motor proficiency and cognitive flexibility in 6- to 12- year- old children

Abstract

The purpose of the present study is to examine the relation between motor proficiency and cognitive flexibility in 6- to 12-year-old children. One hundred and twenty-two children attending regular education were examined on the Test of Gross Motor Development II (TGMD-II) and the Trail Making Test part A and B. Significant relations were found between both subscales (locomotor skills and object control) of the TGMD-II and cognitive flexibility while controlling for age and gender. Effect sizes for locomotor skill were moderate and for object control were moderate to large. The results are being discussed within a neuropsychological framework and suggestions for future intervention studies are given.

Introduction

There is ample evidence for a close relationship between the development of cognitive and motor functions (Diamond, 2000). A neurophysiological mechanism underlying such a close cooperation emerges from fMRI studies indicating an increased activity in the frontal lobe, caudate nucleus, and cerebellum during the performance of either a cognitive or a motor task (Diamond, 2000). It is known that the frontal-circuit is involved in higher order cognitive functions, i.e. executive functions (Bonelli & Cummings, 2007). Executive functions (EF) are critically important in the overall neuropsychological functioning of the developing child and play a fundamental role in the cognitive, behavioral, and social-emotional development of children (Isquith, Crawford, Espy, & Gioia, 2005). The complexity of EF is reflected in a variety of components such as inhibition, selective attention, working memory, planning, concept formation, and fluency (Jurado et al., 2007; Anderson, 2002). Anderson (2002) categorized these sub-functions into four very frequently used EF domains, i.e. attention control, information processing, goal setting, and cognitive flexibility. Interestingly enough these four EF domains do not have a similar developmental trajectory; for example, attention control appears in infancy and it's development is almost complete at age 7, whereas cognitive flexibility develops rapidly around 7 and 9 years and approaches adult levels around 12 years (Anderson, 2002).

Clinical studies so far were focused on the relation between motor development and executive functions in children ranging in age between 4 – 7 years old (Livesey, 2006; Wassenberg, 2005, Roebers & Kauer, 2008). Wassenberg et al. (2005) reported that both qualitative and quantitative aspects of motor proficiency were related to working memory in 5- to 6- year-old school children. Regarding verbal fluency no significant relation was found with qualitative aspects of motor proficiency in 5- to 6-year-old children (Wassenberg et al., 2005). In another study, also examining 5- to 6-year-old children (Livesey, Keen, Rouse, & White, 2006), a significant relation was found between inhibition and fine motor skills. In a more recent study (Roebers & Kauer, 2008), small to moderate correlations were found between cognitive flexibility and three measures of motor skills (i.e. jumping, moving sideways, and fine motor skills) in a sample of 6.5- to 8.5-year-old typically developing children.
Considering that, as mentioned before, cognitive flexibility reaches adult levels around 12 years, it is hypothesized in the present study that the relation between motor skills and cognitive flexibility will be stronger in a sample of typically developing children in a broader age range with older children ranging from 6 to 12 years.

The focus on cognitive flexibility is justified as it plays an important role in the acquisition of new skills, such as learning to read and spell (Acuna, Pardo-Vazquez, & Leboran, 2010). Cognitive flexibility is also of great importance in playing sports, especially in open-skilled team sports like soccer and field hockey (Ziegler, 1994). Furthermore, a suboptimal development of cognitive flexibility can lead to a wide variety of cognitive neuropsychiatric disorders, i.e. learning disabilities, ADHD (Acuna et al., 2010).
In sum the goal of the present study was to examine the relation between motor proficiency and cognitive flexibility, in one hundred twenty-two 6- to 12- year-old children.

Method

Participants

One hundred and twenty-two children (68 boys and 54 girls) between the ages of 6 and 12 years participated in this study. Mean age is 9.22 (1.6), as depicted in Table 1. All children were recruited from one school in the northern part of the Netherlands. Informed consent was obtained from the parents. The procedures were in accordance with the ethical standards for the Medical University of the University of Groningen.

Instruments

The TGMD-2 for assessment of motor proficiency

The Test of Gross Motor Development- second edition (TGMD-2; Ulrich, 2000) was used to assess motor proficiency in the present study. The TGMD-2 consists of two subtests that measure locomotor skills (run, gallop, hop, leap, jump, and slide) and object control skills (strike, bounce, catch, kick, roll and throw).

Table 1. Characteristics of the sample (n=122)

Variables			
Age in years (Mean/SD)	9.22 (1.6)		
Gender (% boys/girls)	55.7/44.3		
Relative level of motor proficiency	Low (range; % of N)	Intermediate (range; % of N)	High (range; % of N)
Locomotor skill	22-38 29.5%	39-42 36.9%	43-48 33.6%
Object control	20-35 35.2%	36-40 34.4%	41-48 30.3%

To assess motor proficiency, the participants were evaluated using different qualitative performance criteria for each test item (3–5 criteria per item). A criterion is scored with a 1 or 0 to indicate whether the skill is present or absent. Each skill was executed twice and a single examiner gave a score for each criterion. The observer then totals the scores for each criterion for the two trials of each skill to obtain the raw skill score. For example, if a skill consists of four criteria, the raw score ranges from 0 to 8 points. The highest raw score for the locomotor skill as well as the object control skill is 48 points.

The TGMD-2 is valid, reliable, norm and criterion referenced assessment of motor proficiency in children (Ulrich & Sanford, 2000). The test-retest reliability is good with a coefficient of .88 for locomotor skill and .93 for object control and .96 for the total test score (Ulrich & Sanford, 2000).

The Trailmaking Test A + B for the assessment of cognitive flexibility
The Trailmaking A+B (TMT; Reitan & Wolfson, 2004) requires participants to connect a series of digits placed in random order on a sheet of paper in ascending order (TMT A) and to connect a series of numbers and letters in ascending order alternating between numbers and letters (i.e. 1-A-2-B, etc.) (TMT B). The TMT A is commonly used as a measure for psychomotor speed, whereas the TMT B is used as a measure for cognitive flexibility. By subtracting the total time of TMT A from the total time of TMT B and thereby removing the motor component in the score of the TMT B, a more objective measure for cognitive flexibility was obtained (Spreen & Strauss, 1998).

Procedure

The TGMD-2 was administered during the regular lessons physical education in the gymnasium of the school, lasting 45 minutes. The TMT was administered during regular school hours. Children were tested individually and both the TGMD-2 and the TMT were administered by well-trained test leaders and according to the manuals of the tests.

Data Analysis

Data analysis of the first part of the study was conducted using SPSS for Windows 15.0. Both subscales of the TGMD, object control and locomotor skill, were used as a measure of motor proficiency and are being divided in three approximately equally sized groups (see Table 1.). Children with a relative low motor proficiency were assigned to group 1, children with relative intermediate motor proficiency to group 2 and children with good motor proficiency to group 3. Two models were being investigated by means of a two-way analysis of covariance (ANCOVA). The first model included object control as a fixed factor and controlled for gender and age as respectively a fixed factor and a covariate and cognitive flexibility as the dependent variable. The second model differed only from the first model that it had locomotor skill as a fixed factor instead of object control.

Interaction effect were examined and dropped from the model when $p > .05$. Partial eta squared effect sizes were reported and $\eta^2 = .01$ is considered small, $\eta^2 = .09$ is moderate and $\eta^2 = .14$ is large (Cohen, 1988). When there were significant main effects for locomotor skill or object control, post hoc pairwise comparisons were done, comparing the adjusted means of cognitive flexibility between group 1 and group 2, group 1 and group 3 and finally group 2 and group 3 of the measures of motor proficiency. A significance level of .05 was used for all analyses except for the post hoc comparisons, where after a Bonferroni correction a significant level of .017 was used.

Results

The relation between object control and cognitive flexibility

The interaction between object control and gender in model 1 was not significant ($F(2,115) = .79$; $p = .46$ and left out of the model. The final model (Table 2) had a significant effect for the covariate age ($F(1,117) = 45.34$; $p < .001$) and a large effect size. Also a significant effect for gender was found ($F(1,117) = 8.53$; $p = .004$) with girls performing better on cognitive flexibility than boys. The effect size was small to moderate.

Finally we found a significant effect for object control (F(2,117) = 6,71; p = .002) with a moderate effect size. Post hoc analysis indicated that the relatively low performing group 1 on motor proficiency performed significant worse than group 2 (p = .006) on cognitive flexibility and group 1 performed significantly worse than group 3 (p = .001). No significant difference between group 2 and 3 was found.

Table 2. Two way ANCOVA with post hoc analyses with cognitive flexibility as dependent variable and object control (model 1) and locomotor skill (model 2) as fixed factor, controlling for gender and age.

Variables	F-value	df	p-value	partial η^2	Post hoc comparisons (p-values)		
Model 1					1 vs 2	1 vs 3	2 vs 3
Object control	6.71	2,117	.002	.103	.006	.001	.28
Gender	8.53	1,117	.004	.068			
Age	45.34	1,117	<.001	.279			
Model 2							
Locomotor skills	4.87	2,118	.009	.076	.81	.007	.009
Age	77.60	1,118	<.001	.397			

The relation between locomotor skill and cognitive flexibility

The interaction between locomotor skill and gender in model 2 was not significant (F(2,115) = 1.09; p = .34) and left out of the model. The resulting model contained a non significant effect for gender (F(1,117)= 1.53; p = .22) and gender was consequently dropped from the model resulting in the final model. The final model had a significant effect for age (F(1,118) = 77.60; p < .001) with a large effect size. Furthermore a significant main effect for locomotor skill was found (F(2,118) = 4.87; p = .009) with a small to moderate effect size. Post hoc analysis revealed a significant effect between group 1 and group 3 (p = .007) and between group 2 and group 3 (p = .009), with group 3 performing better on cognitive flexibility than groups 1 and 2.

Discussion

The goal of the present study was to examine the relation between motor proficiency (TGMD-2) and cognitive flexibility (TMT), in one hundred twenty-two 6- to 12- year old children. The present findings show that both object control and locomotor skill were positively related to cognitive flexibility in 6- to 12- year-old children. In contrast to our expectation however, the effect sizes ranged from small to moderate for the relation between locomotor skill and cognitive flexibility and moderate for the relation between object control and cognitive flexibility while controlling for age and gender.

Considering the effect sizes for object control and cognitive flexibility reported by the present study, one could hypothesize the importance of object control over locomotor skill in relation with cognitive flexibility. Previous research, examining the qualitative aspects of movement and measures of executive functioning, like working memory and verbal fluency (Murray et al., 2006; Wassenberg et al., 2005) could not provide a clear answer with regard to this hypothesis. Wassenberg et al. (2005) used an outcome measure for motor proficiency (Maastricht Motor Test; Kroes et al., 2004) composed of tasks from several domains of motor proficiency – i.e. static balance, dynamic balance, ball skills, diadochokinesis and manual dexterity. However, they did not examine specific relations between these domains and executive functioning, they merely discriminated between a qualitative and a quantitative outcome. Estil and colleagues (2003) did examine specific relations between aspect of motor performance measured by the Movement Assessment Battery for Children (MABC; Henderson & Sugden, 1992), which measures balance skills, ball skills and manual dexterity, and psycholinguistic skills. They found that especially manual dexterity and static balance were related to psycholinguistic skills, but a relation between ball skills and psycholinguistic skills was not observed. However, their study population consisted of 15 5- to 10-year-old children, which prevents drawing solid conclusions based on their findings. Even more important, the M-ABC is a quantitative approach to assess motor performance, rather than a qualitative approach; this might have prevented them from detecting other relations. In order to try to explain the importance of object control over locomotor skill in relation with cognitive flexibility, we argue that object control is a more complicated skill to master. Tasks measuring object control require that children catch a ball or throw a ball to a target; such tasks are more difficult to master than locomotor skills. One could even say that an adequate level of locomotor skill functioning is a prerequisite for mastering object control skills. Because catching or throwing a ball demands that the child is constantly monitoring the ball as it comes towards him, one can hypothesize that this task exerts a greater demand on the nervous system than "just" running or galloping. A child has to adapt constantly to the task at hand because it is constantly changing, therefore the larger effect size between object control and cognitive flexibility seems logical.

The small to moderate effect size for locomotor skill is certainly not a less interesting finding than the moderate effect size for object control. On the contrary, although locomotor skills presumably exert a smaller demand on the nervous system compared to object control tasks. Locomotor skills are more physical demanding than object control tasks and will require a greater level of physical fitness compared to object control. Indeed, a study examining the relation between cardiovascular fitness (6 minute run) and motor proficiency (TGMD) in a sample of 444 children with intellectual disability found a correlation of .36 between cardiovascular fitness and locomotor skill and a correlation of .25 between cardiovascular fitness and object control (Frey & Chow, 2006). We argue that being more active leads to a higher level of physical fitness which in turn will lead to a higher level of motor proficiency especially in locomotor skill. Within this scope it is worrisome that precisely this type of physical activity is decreasing in children, considering the alarming increase in sedentary life style (Guran & Bereket, 2011). It is known that an increase in sedentary lifestyle not only will lead to obesity (Tremblay, Colley, Saunders, Healy, & Owen, 2010) but also has a negative effect on cognition (Vaynman & Gomez-Pinilla, 2006).

The present findings further show that age was an important factor in both model 1 and model 2. This is in accordance with Diamond (2000), who stated that the development of executive functions continues on well into the teenage years and this development runs parallel with the development of brain structures, such as the prefrontal cortex and the cerebellum. Besides age, we also found gender differences on cognitive flexibility in the model with object control which is in accordance with a study done by Martins et al. (2005), who found that girls were better in information processing and had a higher cognitive flexibility than boys. This effect for gender however, was not found in the model with locomotor skill.
In summary, we found significant relations between two measures of motor proficiency, that is, object control and locomotor skill, and cognitive flexibility. To our knowledge no other study has examined the relation between motor proficiency and cognitive flexibility in this age group of 6- to 12- year-old children. Cognitive flexibility is a component of executive functioning that plays a crucial role in the acquisition of new

skills, such as learning to read and learning to spell (Acuna et al., 2010). Therefore, the next step for future research should be establishing a causal relation between motor proficiency and cognitive flexibility by designing an intervention study focussing on improving cognitive flexibility by training children in motor skills. Our results would suggest that a motor intervention should focus on object control as well as locomotor skills.

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Chapter 6

The Relationships between motor proficiency and physical fitness with cognitive flexibility in school-aged children.

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Submitted

The relationships between motor proficiency and physical fitness with cognitive flexibility in school-aged children.

Abstract

Objective: To investigate the relationships between motor proficiency, physical fitness, and cognitive flexibility in one hundred twenty-two typically developing children aged 6- to 12- years- old.

Methods: Motor proficiency was assessed using the Test of Gross Motor Development-2. Physical fitness, in terms of the VO2 max, was estimated using the 20m progressive shuttle-run test. Cognitive flexibility was studied in a set-shifting paradigm and was assessed using the Trailmaking Test A+B. With the use of structural equation modelling two models were designed, for object control and locomotor skill respectively. Age and gender were incorporated into both models in order to accurately predict set-shifting performance.

Results: The results showed a significant effect of object control and physical fitness on cognitive flexibility. The effect of object control on cognitive flexibility was almost twice as strong as the effect of physical fitness. There was an indirect effect of locomotor skill on cognitive flexibility, with physical fitness mediating this effect.

Conclusions: In order to unify the unique relationships of motor proficiency and physical fitness the cardiovascular fitness hypothesis should be elaborated with findings associated with the motor learning hypothesis. Specific neuro-physiological adaptations in the brain underlie these unique relationships.

Introduction

Executive functioning (EF) can be categorized into four frequently used EF domains, i.e. attention control, information processing, goal setting, and cognitive flexibility (Anderson, 2002). EF is critically important in the overall neuropsychological functioning of the developing child and plays a fundamental role in the cognitive, behavioural, and social-emotional development of children (Isquith, Crawford, Espy, & Gioia, 2005). Deficits in various aspects of EF are central in the development of learning disabilities and developmental disorders (Barkley, 1997; Pennington & Ozonoff, 1996).

An important aspect of EF for a developing child is cognitive flexibility. Cognitive flexibility can be defined as the ability to protect an ongoing task from disruption without compromising the flexibility that allows the rapid execution of other tasks when appropriate (Monsell, 2003). Cognitive flexibility is usually studied in 'set-shifting tasks' or 'task switch paradigms' in which participants rapidly switch back and forth between two or more tasks requiring simple discriminations between a set of multidimensional stimuli (Meiran, 1996). Cognitive flexibility develops dramatically during childhood and has been shown to be involved in the development of a theory of mind, language and arithmetical skills (Chevalier & Blaye, 2008).

In the past decades many studies have been published either on the relationship physical fitness (also paraphrased as cardiovascular fitness or aerobic fitness) and executive functions or the relation between motor performance and executive functions.

The cardiovascular fitness hypothesis states that improved physical fitness (PF) through regular participation in physical activity can mediate cognitive performance (Barnes, Yaffe, Satariano, & Tager, 2003). Regular participation in physical activity is associated with a variety of underlying physiological mechanisms, like cerebral structure, increased cerebral blood flow and increased brain-derived neurotrophic factors, which have been associated with cognitive performance (Etnier, Nowell, Landers, & Sibley, 2006). Several studies demonstrated a positive effect of improved PF on executive functioning across different ages (Buck, Hillman, & Castelli, 2008; Etnier & Berry, 2001; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009). Also in the task-switching paradigm a positive relationship was found for PF (Kramer et al., 1999) in elderly, without dementia. Meta-analysis did not provide consistent support for the cardiovascular fitness hypothesis in adults and the elderly (Colcombe & Kramer, 2003; Etnier et al., 2006; Etnier et al., 1997). On the other hand, another meta-analysis did show positive relations between exercise and several cognitive domains, like concentration and executive control, but not between exercise and memory performance in children and adolescents (Sibley & Etnier, 2003). A more recent review and study however did found a relation between physical fitness and memory (Chaddock, Hillman, Buck, & Cohen, 2011; Chaddock, Pontifex, Hillman, & Kramer, 2011).

Second, a more qualitative approach of the assessment of motor performance, motor proficiency (MP), has gained more scientific interest over the last decade in relationship with EF. Assumed is that the development of MP and EF are fundamentally intertwined in the sense that they share equally protracted timelines; in addition the striatal pathway between the cerebellum and the prefrontal cortex is involved in both functions (Diamond, 2000). For instance, it was shown that the age at which important motor milestones are achieved – i.e. the ability to stand without support - is positively related to working memory later on in life (Murray et al., 2006). Furthermore, both qualitative and quantitative aspects of MP were related to working memory, but qualitative aspects were not related to verbal fluency in 5- to 6- year-old school children (Wassenberg et al., 2005).

The present study was designed in order to simultaneously examine the relationship between MP and PF with cognitive flexibility in a population of 6- to 12- year-old typically developing children. By simultaneously examining both MP and PF one could determine the unique contribution of each on cognitive flexibility. To our knowledge, no other study before has attempted to do so. As both MP and PF are interrelated (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2008; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006) it is possible that the relationship between MP and EF can also be attributed to the cardiovascular fitness theory. However, if unique relations could be established the cardiovascular fitness hypothesis should be reconsidered in an attempt to unify both the effects of MP and PF in order to design useful motor-based interventions to aid the EF in children.

Methods

Population

One hundred and twenty-two typically developing children (68 boys and 54 girls) between the ages 6 and 12 years participated in this study. No statistical differences between boys and girls were found with respect to age, height, weight and their Body

Mass Index (BMI), as depicted in Table 1. Informed consent was obtained from the parents. The procedures were in accordance with the ethical standards of the Faculty of Medical Sciences of the University Medical Centre Groningen, University of Groningen.

Instruments

The TGMD-2 for the assessment of motor proficiency (MP)

The Test of Gross Motor Development- second edition (TGMD-2; Ulrich & Sanford, 2000) was used to assess motor proficiency in the present study. The TGMD-2 consists of two subtests that measure locomotor skills (LS; run, gallop, hop, leap, jump and slide) and object control skills (OCS; strike, bounce, catch, kick, roll and throw).

To assess MP, the participants were evaluated using different qualitative performance criteria for each test item (3–5 criteria per item). A criterion is scored with a 1 or 0 to indicate whether the skill is present or absent. Each skill was executed twice and a single examiner gave a score for each criterion. The observer then totals the scores for each criterion for the two trials of each skill to obtain the raw skill score. For example, if a skill consists of 4 criteria, the raw score ranges from 0 to 8 points. The highest raw score for the OCS as well as the LS is 48 points.

Table 1. Descriptives and t-test statistics for boys and girls.

	Boys (n=68)		Girls (n=54)				
Variables	Mean	SD	Mean	SD	t	df	*p*-value
Age (yrs)	9.23	1.5	9.21	1.7	.08	120	.94
Length (cm)	141.31	10.8	138.90	12.3	1.17	120	.24
Weight (kg)	34.23	8.4	32.54	9.6	1.04	120	.30
BMI	16.94	2.5	16.61	2.8	.68	120	.50

The TGMD-2 is valid, reliable, norm and criterion referenced assessment of MP in children. The test-retest reliability is good with a coefficient of .93 for OCS, .88 for LS and .96 for the total test score (Ulrich & Sanford, 2000).

The 20m progressive shuttle-run test for the assessment of physical fitness (PF)
The Maximal Multistage 20 Meter Shuttle Run Test (20-MST) is used to measure cardiorespiratory endurance. The 20-MST is validated in schoolchildren as an estimate of maximal aerobic power (VO2max; Boreham, Paliczka, & Nichols, 1990; Vanmechelen, Hlobil, & Kemper, 1986). The 20-MST is a maximal running test starting at a running speed of 8.0 km/h, which is increased every minute and in which the pace is set by an audio signal. Performing the test, one runs a 20-meter course back and forth. The subjects were instructed to keep pace with the signal until exhaustion, as defined as unable to reach the 20m line consecutively twice with the beep.
The test-retest reliability coefficients range from 0.89 for children to 0.95 for adults (Leger, Mercier, Gadoury, & Lambert, 1988).

The Trailmaking Test A + B for the assessment of cognitive flexibility (set-shifting)
The Trailmaking A+B (TMT; Reitan & Wolfson, 2004) requires participants to connect a series of digits placed in random order on a sheet of paper in ascending order (TMT A) and to connect a series of numbers and letters in ascending order alternating between numbers and letters (i.e. 1-A-2-B, etc.) (TMT B). The TMT A is commonly used as a measure for psychomotor speed, whereas the TMT B is used as a measure for set-shifting. By subtracting the total time of TMT A from the total time of TMT B a more objective measure for set-shifting can be obtained, because of removing the motor component out of the TMT B (Spreen & Strauss, 1998).

Procedure
The TGMD-2 was administered during the regular lessons physical education in a gymnasium, lasting 45 minutes. The children were tested individually. Well-trained test leaders administered each item of the TGMD-2. The order of the tests of the TGMD-2 was randomised to eliminate the influence of fatigue. The 20-MST test was performed on a separate day to eliminate the influence of fatigue on the performance on the TGMD-2 and the TMT.

The TMT was administered during regular school hours. Well-trained test leaders tested the children individually.

Statistical Analysis
Two structural equation models, one OCS and one for LS respectively, were designed. Demographic variables, age and gender respectively, were also included into the model as possible predictors of OCS (in model 1), LS (in model 2), PF, and cognitive flexibility. Furthermore, in model 1, it was hypothesized that OCS and PF are a predictors of cognitive flexibility. In model 2 it was hypothesized that LS and PF are predictors of cognitive flexibility and a bi-directional relationship between locomotor skills and physical fitness was specified, since there was no consensus in the literature about the direction of this relationship.

A stepwise approach was used to drop causal relationships that were not significant (t-value smaller than -1.96) from the model. Three goodness-of-fit measures were used to describe the final model. The minimum fit function Chi-square p-value should be larger than .05. The minimum fit function is a measure of the overall fit of the model to the data. The standardized residual mean square (SRMR), a value smaller than .08 is an indication of an acceptable fit (Browne & Cudeck, 1992). And the goodness of fit index (GFI), should have a value of greater than .90 (Jöreskog & Sörbom, 1993).

Results

In Table 2. the bivariate correlations between all the variables of interest are presented.

Table 2. The correlations between the variables used in the structural equation models

	Object control	Locomotor skill	Cognitive flexibility	Physical fitness	Gender	Age
Cognitive flexibility	-.44*	-.21*	1			
Physical fitness	.40*	.21*	-.36*	1		
Gender	-.42*	.41*	-.15	-.30*	1	
Age	.46*	.02	-.61*	.38*	-.01	1

* Significant at p<.05

The full model with OCS was a saturated model with a perfect fit to the data (minimum fit function Chi^2 (0) = .00, p = 1.00), but consisted of one non-significant relationship. The relationship between OCS and PF was not significant (t=1.42) and was dropped from the model. The final model (see Figure 1.) had an excellent overall fit (minimum fit function Chi^2 (1) = 2.05, p =.15; GFI = .99; SRMR = .03) and contained significant negative relationships from age, gender, OCS and PF to cognitive flexibility. Higher scores on age, gender, OCS and PF resulted in a better performance on cognitive flexibility. Furthermore, negative relationships from gender to OCS and PF, indicating that boys perform better than girls on these two domains. And finally, a significant positive relationship from age to OCS and PF was found, indicative of a better performance as children get older.

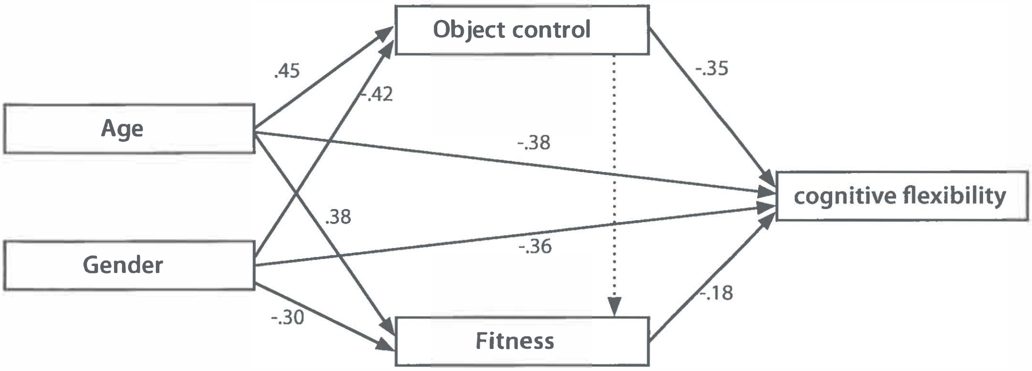

Figure 1. Structural equation model with object control as a measure of motor proficiency.

The full model for LS was a saturated model with a perfect fit to the data (minimum fit function Chi^2 (0) = .00, p = 1.00), but consisted of three non-significant relationships. The relationship between age and LS was not significant (t = .20) and was dropped from the model. The relation from PF to LS was also not significant (t=.24) and dropped from the model. Subsequently, the relationship between LS and cognitive flexibilitywas found to be not significant (t = 1.03) and was dropped from the model. This resulted in the final model (see Figure 2.), with an excellent overall fit (minimum fit function Chi^2 (2) = 1.12, p = .57; GFI = 1.00; SRMR = .019). The final model had significant negative relationships from age, gender and PF to cognitive flexibility. Higher scores on age, gender and PF resulted in a better performance on cognitive flexibility.

A significant positive relationship exists between gender and LS. A significant positive effect of LS on PF was found. Finally, a significant negative relation between gender and PF was found.

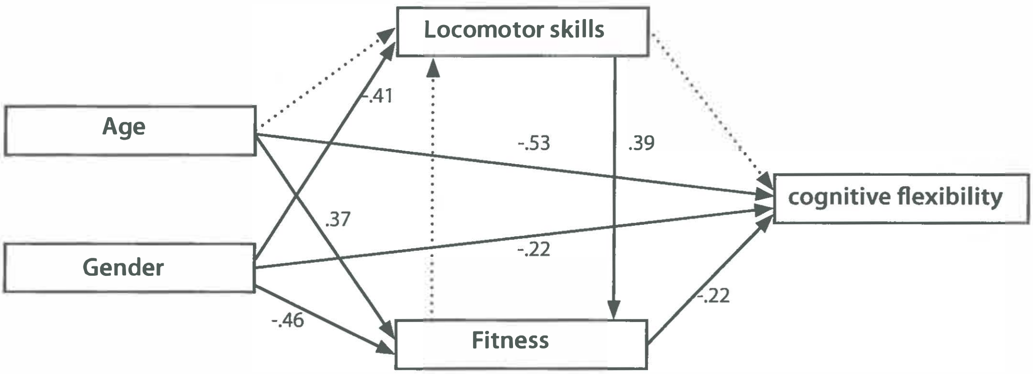

Figure 2. Structural equation model with locomotor skill as a measure of motor proficiency.

Discussion

Relationships between MP and PF separately with EF have been studied frequently in the past. However, cognitive flexibility has received little attention over the years in both these domains of research. As this aspect of EF plays an important role in the development of a Theory of Mind, language, and arithmetical skills (Chevalier & Blaye, 2008) it is of great importance in the development of children. To our knowledge, for the first time aspects of MP and PF where examined simultaneously in relationship with EF. As both MP and PF are interrelated (Barnett et al., 2008; Wrotniak et al., 2006) simultaneously examining the effects of MP and PF on cognitive flexibility will provide more insight in the unique effect these factors have on the level of cognitive flexibility in typically developing children.

The present study showed that OCS (see Figure 1) had a positive effect on set-shifting, a measure of cognitive flexibility; moreover, a smaller direct effect of PF on set-shifting was found. Both relationships persisted next to large effects of age and gender.

Recent studies have shown that structural and functional changes can occur throughout the human brain including the prefrontal cortex and the cerebellum, as a result of motor learning (Taubert et al., 2010). Whereas historically EF, like cognitive flexibility, has been exclusively attributed to the prefrontal cortex, a recent fMRI showed that particularly the cerebellum, as part of the fronto-cerebellar network, is important for cognitive flexibility (Lie, Specht, Marshall, & Fink, 2006). In addition, the cerebellum is involved in the learning of visuomotor skills (Flament, Ellermann, Kim, Ugurbil, & Ebner, 1996); a prerequisite for OCS. It is hypothesized here that learning a motor skill elicits structural and functional changes throughout the fronto-cerebellar network. Changes in the fronto-cerebellar network have been shown to be related to improvements in EF mediated by the prefrontal cortex (Goto, Yang, & Otani, 2010).

The timeframe in which these neurophysiological adaptations occurred favors fast adjusting neurophysiological adaptations, like synaptic plasticity (Driemeyer, Boyke, Gaser, Buchel, & May, 2008). The occurrence of synaptogenesis has been confirmed in animal studies (Anderson et al., 1994; Black, Isaacs, Anderson, Alcantara, & Greenough, 1990) and in a human study using a visuomotor skill, 3-ball juggling (Driemeyer et al., 2008), where synaptic plasticity has been observed in the occipito-temporal cortex. Importantly, these studies have shown that these structural and functional changes in the brain are exclusively associated with motor learning and cannot be elicited by merely being physical active (Anderson et al., 1994; Black et al., 1990; Driemeyer et al., 2008).

Contrary to model 1, LS did not show a direct effect on cognitive flexibility. The absence of this direct effect could invalidate the proposed motor learning hypothesis described above. However, the motor skill hypothesis must yield an additional premise: The motor skill that is learned must have a certain level of complexity in order to elicit neurophysiological adaptations in the human brain. The level of complexity must be seen in the light of the developing child. Whereas LS and OCS start developing simultaneously in early childhood, OCS are not fully developed until adolescence (Diamond, 2000). The children in the present study scored significantly higher on LS compared to OCS. Similar results have also been found in children with intellectual disabilities and children with learning disabilities (Westendorp, Hartman, Houwen, Smith, & Visscher, 2011; Westendorp, Houwen, Hartman, & Visscher, 2011). This could indicate that children attain a proficient level of LS earlier on in childhood compared to OCS.

Both models showed a small ES (regression coefficient = .18) of PF on set-shifting. A meta-analysis also showed a small ES (Hedge's g = .32) between PF and cognition in children (Sibley & Etnier, 2003); however the studies in that meta-analysis did not take the effect of MP into consideration. The significant relationship between PF and set-shifting in both models supports the existing evidence of the cardiovascular fitness hypothesis. The cardiovascular fitness hypothesis states that EF can be improved by gains in cardiovascular fitness, by means of various physiological adaptations like increased cerebral blood flow, increased brain-derived neurotrophic factors and structural changes in the brain. Model 2 also showed a direct relationship between LS and PF. The direction of the effect seems to indicate that LS are a prerequisite for improving PF.

Age was an important factor for OCS, PF and set-shifting. This is in accordance with existing literature as aspects of MP, like visuomotor skill (Diamond, 2000; Hands, 2008; Okely, Booth, & Patterson, 2001), PF(Hands, 2008; Okely et al., 2001) and cognitive flexibility (Diamond, 2000; Martins et al., 2005) develop well into the teenage years. No effect of age on LS was found. The absence of this relationship could support the earlier maturation of LS, as mentioned earlier.

Boys performed better on OCS and PF, whereas girls performed better on LS and cognitive flexibility. Girls perform better on information processing and have a higher level of cognitive flexibility (Martins et al., 2005; Williams et al., 1995) compared to boys. Similar gender differences on the TGMD-2 were not confirmed in a recent study with a similar age group (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010). However, in a group of preschoolers boys had a higher total OCS score; whereas girls had a higher total LS score. Although no official data on sports participation were collected as part of the present study the observed differences between boys and girls could be due to differences in their engagement in different physical activities.

It is of particular interest to examine whether the present findings can be replicated in children with a specific diagnosis. For instance, problems in motor development have been shown to exist in children with attention deficit hyperactivity disorder (Rommelse et al., 2009), developmental language impairments (Visscher, Houwen, Scherder, Moolenaar, & Hartman, 2007; Webster et al., 2006) and intellectual disabilities (Hartman, Houwen, Scherder, & Visscher, 2010; Vuijk, Hartman, Scherder, & Visscher, 2010). Future research should always incorporate aspects of MP when studying the relationship between motor performance with EF in children. When possible, MP and PF should be studied simultaneously in relationship with EF in order to gain even more insight.

Conclusions

The present findings, supported by previous brain imaging research, provide support for extending the cardiovascular fitness hypothesis with findings associated with the motor learning hypothesis. This hypothesis states that when learning a motor skill structural and functional changes occur in the fronto-cerebellar network. EF is directly affected by these changes in the fronto-cerebellar network. The complexity of the skill relative to the developing child should be considered. Also, evidence supporting the cardiovascular fitness hypothesis was presented here. Future research should always take the complexity of skill relative to the developmental period of the study population into account when trying to replicate and extend the present findings. The results of the present study justify future intervention studies that aid in the design of useful, motor-based interventions focused on complex aspects of MP and PF to improve cognitive flexibility of the developing child.

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Chapter 7

General discussion

Background

Neuropsychological research of children with developmental disabilities, for example ADHD, autism spectrum disorders and dyslexia, where the integrity of the brain is affected, showed that the prevalence of motor problems is higher in these groups compared to the population of typically developing children (e.g. Dewey, Wilson, Crawford, & Kaplan, 2000; Green, Baird, Sugden, & Chambers, 2005; Maski, Jeste, & Spence, 2011). In this thesis the relation between general cognitive functioning (intelligence) and motor problems is examined in four groups of children with different levels of intellectual functioning; i.e. mild intellectual disability (MID), borderline intellectual functioning (BIF), children with learning disorders and IQ>80, and typically developing children. The first three groups consisted of children attending special education and the children in the last group are attending regular education. Motor performance (i.e. manual dexterity, balance, and object control) of the children attending special education was assessed with the Movement ABC (MABC; Henderson & Sugden, 1992), while the typically developing children were assessed on motor proficiency with the Test for Gross Motor Development-second edition (TGMD-2; Ulrich & Sanford, 2000). Furthermore, in the groups of children attending special education the relation between motor performance and academic achievement (i.e. reading, spelling, and mathematics) was examined. While in the group of typically developing children the relation between motor proficiency and physical fitness and cognitive flexibility was examined. If a relation exists, than this thesis can contribute in an important way to the development of motor-based intervention programs in order to improve cognitive functioning and academic achievement.

Presentation of the main results

In the second chapter the degree of motor impairment in children with MID and children with BIF (all attending schools for special education) were compared to the normative population. The first part of the study showed that after combining the percentages of the children with borderline motor problems and definite motor problems, 81.8% of the children with MID have some degree of motor problems as compared to 60.0% of the children with BIF. The second part of the study, the comparison of two groups of children with MID or BIF showed small to moderate effect sizes on motor performance as measured by the total score of the MABC as well as the three subscale scores (i.e. manual dexterity, ball skills, and balance).

In the third chapter a sample of 137 children with learning disabilities (IQ>80) attending special needs schools were examined with the Movement ABC in order to determine the percentage of children with motor problems. This study showed that overall motor performance was quantitatively impaired in 50.4% of the children who performed below the 15th percentile on the MABC (total score) indicating that half of these children have some degree of motor problems. A closer look at the subscales of the MABC shows that 52.6% of the children had borderline or definite motor problems on manual dexterity, 40.9% on ball skills, and 33.6% on balance. It appears that manual dexterity (i.e. tasks that require fine motor skills) is the most sensitive marker in children with learning disabilities even though no statistical analysis to confirm this has been conducted.

When taking a look at their academic performance on reading, spelling, and mathematics it was found that the children on average did not master around 50% of the academic skills expected given their didactical age.

The partial correlations between the measure of motor performance and academic achievement while controlling for IQ showed small to moderate effect sizes between the total score on the MABC and spelling and mathematics. Taking a closer look at the subscales of the MABC, small to moderate relations were found between ball skills and reading, between manual dexterity and spelling, and between balance and mathematics.

In the fourth chapter we wanted to know if the relations between motor performance and academic achievement also applies for children with mild intellectual disability and borderline intellectual functioning. No significant effects were found for any of the three subscales of the MABC on reading and spelling while controlling for intellectual disability group (i.e. MID or BIF). In contrast, manual dexterity, ball skills, and balance all showed significant relations with mathematics with moderate effect sizes.

In the fifth chapter we examined the relation of motor proficiency (a qualitative measure of motor performance) with cognitive flexibility in 6- to 12-year-old typically developing children attending regular education. Small to moderate effects were found between locomotor skills and cognitive flexibility and a moderate effect was found for object control and cognitive flexibility while controlling for age and gender.

In the sixth chapter the effects of motor proficiency and physical fitness on cognitive flexibility simultaneously was examined using structural equation modeling. In two separate models, one with age, gender, physical fitness, and object control and one with age, gender, physical fitness, and locomotor skills showed interesting results. Examination of the model with locomotor skill as a measure of motor proficiency showed that physical fitness had a direct positive effect on cognitive flexibility while the relation between locomotor skill and cognitive flexibility was not significant. The model with object control showed that both physical fitness and object control had direct effects on cognitive flexibility.

General conclusions

A relation between general cognitive functioning (measured with IQ tests) and motor functioning exists with the proportion of children showing motor impairment increases when general cognitive functioning decreases. Some, but not all, measures of motor performance are correlated with academic achievement measures in children attending special education. In typically developing children associations between motor proficiency and cognitive flexibility were found. These results, in combination with results from previous research, argue for a robust relation between different aspects of motor functioning and cognition.

Implications for future research

More research on children with intellectual disabilities.

The body of research on children with mild intellectual disability (MID) and borderline intellectual functioning (BIF) is relatively limited compared to children in the general population. More research should be conducted in this population of vulnerable children, especially on relations between motor functioning and other cognitive functions next to executive functions. More associations between physical activity, motor performance, and cognitive functions in these children, as has already been found in large groups of cognitive higher functioning children, may lead to the development of intervention studies, aimed at improving cognition.

Development of interventions

The present thesis repeatedly found relations between different aspects of motor functioning and different aspects of cognition and not only in typically developing children but also in children attending special education. The fact that this relation between motor functioning and cognition was repeatedly found indicates that it concerns a robust relationship even though not every aspect of motor functioning yielded significant associations with every aspect of cognitive functioning examined in this thesis. It is therefore surprising that only a few researchers examined the effect of a motor-based intervention on cognition. For example, a controversial study by Reynolds (2007; 2003) found a positive effect of a daily exercise intervention at home, including the use of a balance board, catching and throwing of bean bags, and the practice of dual tasking, on, among others, reading fluency and verbal fluency in a group of children with reading disabilities. A more recent study found a positive effect on attention and working memory in a large cohort of children from main stream schools (Hill et al., 2010), while another recent study (Verret, Guay, Berthiaume, Gardiner, & Béliveau, 2010) found improvements in children diagnosed with ADHD on level of information processing, visual search, and sustained attention. Finally, executive functions of children with ADHD responded positively to physical exercise (Gapin & Etnier, 2010).

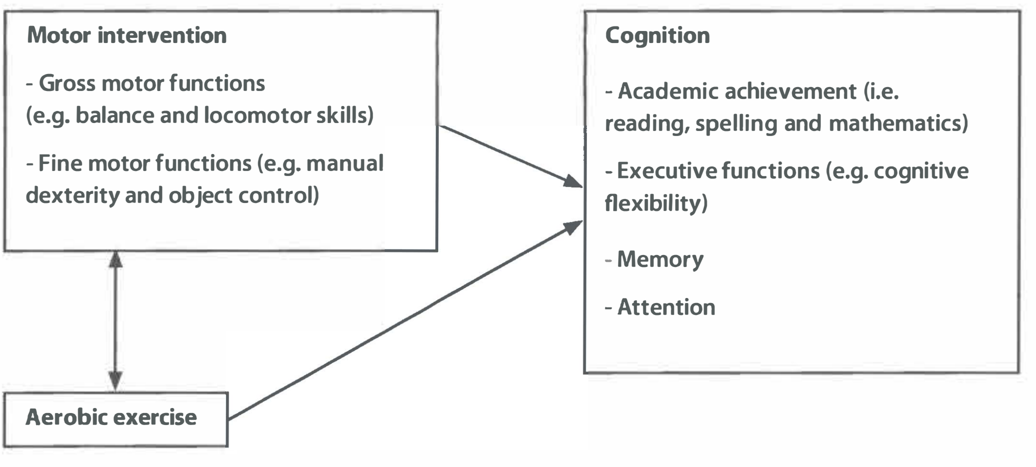

Figure 1. A schematic representation of a proposed future intervention on motor functioning and aerobic exercise in order to improve cognitive functioning.

Future research should focus on designing an intervention combining physical exercise and motor skills (in particular object control and fine motor skill) in order to improve cognition (see Figure 1) Based on the results of the study described in chapter six, it is important that when designing a motor based intervention, the motor skills that are being trained are not yet mastered. In addition, a certain level of complexity is necessary to elicit neurophysiological adaptations in the human brain (Hill & Schneider, 2006). Depending on age and diagnoses of a child, most suitable motor skills imply fine motor skills and eye-hand coordination.

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Summary

The goal of this thesis was to examine the association motor functioning and cognitive functioning in school-aged (6 through 12 years old) children by examining four groups of children. The first group consisted of children with mild intellectual disability (MID), that is, children with an IQ between 50 and 70. The second group consisted of children categorized as borderline intellectual functioning (BIF). These children have IQ-scores ranging from 71 through 84. The third group consisted of children attending special education with a learning disability (LD). Children with learning disabilities are being described as children with below average intelligence or higher (IQ> 80) with problems acquiring academic skills in reading, spelling, and mathematics that cannot be attributed to their IQ. The fourth group consists of children attending regular education and IQ scores are assumed to be in the normal range.

Two different tests are used to examine motor development. The first three groups with children attending special education were examined with the Movement ABC (MABC) for children. The MABC is a frequently used test to determine quantitative motor problems in children on three important motor domains (i.e., manual dexterity, ball skills, and balance). Motor performance of the children attending regular education was examined with the Test for Gross Motor Development-second edition (TGMD-II), because these children have a low incidence of motor problems. This test is therefore a qualitative measure of motor performance (motor proficiency) and contains two subscales (i.e. locomotor skill, and object control).

The academic achievement scores on reading, spelling, and mathematics are extracted from the personal files at school and are taken as measures of cognition for the three groups of children attending special education. The personal files also contain the IQ-scores since an assessment of cognitive functioning is a prerequisite for referring a child to special education. The group children attending regular education are being examined using the Trail Making Test, a test used for measuring cognitive flexibility.

In the second chapter, the relation between intelligence and motor performance is examined by comparing a group of children with mild intellectual disability to a group of children with borderline intellectual functioning using the Movement ABC as a quantitative measure of motor performance. Children with an intellectual disability had significantly more borderline and definite motor problems (81.8% of the children with MID and 60.0% of the children with BIF) than the normative sample and there was an association between degree of ID and performance on manual dexterity, ball

skills, and balance skills. This study highlights the importance of improving motor skill performance in both children with borderline and mild ID, and the results support the notion that the level of motor and cognitive functioning are related in children with ID.

In the third chapter, the motor profile of a large group of children with learning disabilities was examined and motor performance was related to academic achievement scores on reading, spelling, and mathematics by means of partial correlations. The results showed that, compared to the available norm scores, 52.6% of the children tested had borderline or definite motor problems on manual dexterity, 40.9% on ball skills, and 33.7% on balance skills. Furthermore, after controlling for IQ, significant small to moderate partial correlations were found between spelling and mathematics and the MABC total score, as well as small to moderate correlations between mathematics and balance, between reading and ball skills, and between spelling and manual dexterity. The fact that these associations were found in a heterogeneous and ecological valid group of children attending special needs schools strengthens the idea of a general theory of the high comorbidity rates between children with neurodevelopmental disorders and motor problems.

The fourth chapter describes the relation between motor performance and academic achievement on reading, spelling, and mathematics in children with mild intellectual disability and borderline intellectual functioning. Children within these groups have academic achievement difficulties with all academic skills; i.e. reading, spelling, and mathematics, but are not considered learning disabled because their low IQ is thought to be responsible for their academic problems. None of the motor domains showed significant associations with reading and spelling, in contrast, manual dexterity, ball skills, and balance all showed significant relations with mathematics with moderate effect sizes. We hypothesize that differences in cortical contributions to math and subcortical contributions to reading and spelling in children with a lowered IQ is at the foundation of the found correlations between motor performance and mathematics in our sample.

In the fifth chapter motor proficiency of typically developing children attending a regular elementary school and are assumed to have an IQ within the normal range was assessed with the TGMD-II. This chapter focused on the relation between motor proficiency (the quality of movement) and cognitive flexibility (set-shifting) as a measure of cognition. Cognitive flexibility is the ability to adapt to behavior according to the context requirements and problems in this domain can lead to a wide variety of neuropsychiatric disorders such as learning disabilities and ADHD. Significant positive relations were found between both subscales (locomotor skills and object control) of the TGMD-II and cognitive flexibility while controlling for age and gender. Effect sizes for locomotor skill were moderate and for object control were moderate to large.

The sixth chapter also examined the relation between motor proficiency and cognitive flexibility in typically developing children but now in combination with physical fitness. Previous research already has established a relation between motor performance and cognition as well as the relation between physical fitness and cognition, but the results of this study showed a significant effect of object control and physical fitness on cognitive flexibility. The effect of object control on cognitive flexibility was almost twice as strong as the effect of physical fitness. There was an indirect effect of locomotor skill on cognitive flexibility, with physical fitness mediating this effect. This is an interesting finding for researchers developing an intervention program for children in order to improve cognition, as these results suggests that an intervention should not only focus on increasing motor skills but should also aim to improve physical fitness.

In chapter 7 the main findings and implications of the study are being review in the general discussion.

Samenvatting

Het doel van dit proefschrift was om de samenhang tussen motorisch functioneren en cognitief functioneren te onderzoeken bij kinderen van 6 tot 12 jaar oud die speciaal basisonderwijs volgen of op een reguliere basisschool zitten. Er waren 4 groepen. De eerste groep bestond uit kinderen met een licht verstandelijke beperking, dat wil zeggen, deze kinderen hebben een IQ tussen de 50 en de 70. De tweede groep bestond uit kinderen met een "borderline" verstandelijke beperking. Deze kinderen hebben een IQ tussen de 71 en 84. De derde groep bestond uit kinderen uit het speciaal basisonderwijs met leerproblemen. Deze kinderen hebben een benedengemiddeld IQ of hoger (IQ>80) en hebben problemen met het aanleren van academische vaardigheden die niet toegeschreven kunnen worden aan hun IQ zoals lezen, spellen en rekenen. De vierde groep bestaat uit kinderen die op een reguliere basisschool zitten en waarvan we uitgaan dat hun IQ zich in de normale range bevindt.

Twee verschillende tests zijn gebruikt om het motorisch functioneren te onderzoeken. De eerste 3 groepen, bestaande uit kinderen die op het speciaal basisonderwijs zitten, zijn onderzocht met de Movement ABC (MABC) voor kinderen. De MABC is een veelgebruikte test om problemen met het motorisch functioneren op 3 belangrijke domeinen (i.e. handvaardigheid, balvaardigheid en balans) te kwantificeren. Het motorisch functioneren van de kinderen op het reguliere onderwijs is onderzocht met de Test voor Grove Motorische Ontwikkeling (TGMD-II) omdat deze kinderen, gezien het feit dat ze op het reguliere onderwijs zitten, weinig motorische problemen laten zien. Deze test is dan ook een kwalitatieve maat voor motorisch functioneren en bestaat uit 2 sub-schalen (i.e. locomotorische vaardigheden en object controle).

De academische prestaties op lezen, spellen, en rekenen van de kinderen zijn gebaseerd op de gegevens van het Cito leerlingvolgsysteem en zijn terug te vinden in het persoonlijke dossier van de leerlingen, evenals hun IQ-scores. Deze prestaties zijn als maten van cognitief functioneren gebruikt voor de kinderen die in de 3 groepen zitten die speciaal basisonderwijs volgen. De groep kinderen op het reguliere onderwijs zijn onderzocht met de Trailmaking Test (TMT) die gebruikt wordt om cognitieve flexibiliteit te meten.

In hoofdstuk 2 is de relatie onderzocht tussen intelligentie en motorisch functioneren door de kinderen in de groep met milde intellectuele beperking (MIB) te vergelijken met kinderen met "borderline" intellectueel functioneren (BIF) door de MABC als kwantitatieve maat voor motorisch functioneren te gebruiken. Kinderen met een intellectuele beperking laten significant meer problemen zien met motorisch functioneren (81.8% van de kinderen met MIB en 60.0% van de kinderen met BIF) in vergelijking met de normen in de algemene populatie. Tevens is er een samenhang gevonden tussen de mate van intellectuele beperking en het functioneren op handvaardigheid, balvaardigheid en balans waarbij de motorische problemen toenemen naarmate het IQ lager wordt. Gezien de omvang van de problemen met motoriek bij kinderen met een intellectuele beperking is het belangrijk dat daar tijd en aandacht aan wordt besteed door middel van interventies om deze problemen aan te pakken.

In hoofdstuk 3 is het motorisch profiel onderzocht bij een grote groep kinderen met leerproblemen en is motorisch functioneren gerelateerd aan de prestaties op lezen, spellen, en rekenen door middel van partiële correlaties. De resultaten laten zien dat, vergeleken met de beschikbare normscores, 52.6% van de kinderen motorische problemen lieten zien op handvaardigheid, 40.9% van de kinderen op balvaardigheid, en 33.7% van de kinderen balans. Verder, controlerend voor IQ-score, zijn er kleine tot matige significante partiële correlaties gevonden tussen lezen en spellen enerzijds en de totaalscore op de MABC, tussen rekenen en balans, tussen lezen en balvaardigheid, en tussen spellen en handvaardigheid. Het feit dat deze associaties zijn gevonden in een heterogene en ecologische valide groep kinderen op het speciaal basisonderwijs draagt bij aan het idee van een algemene theorie waar de hoge co-morbiditeit tussen kinderen met ontwikkelingsproblemen en motorische problemen wordt uitgelegd.

Hoofdstuk 4 beschrijft de relatie tussen het motorisch functioneren van kinderen met een milde intellectuele beperking of "borderline" intellectueel functioneren en hun prestaties op lezen, spellen en rekenen. Deze kinderen hebben leerachterstanden op alle academische vaardigheden maar worden niet als kinderen met leerproblemen beschouwd omdat aangenomen wordt dat hun lage IQ verantwoordelijk is voor hun problemen met schoolse vaardigheden. Geen van de motorische deelgebieden was gerelateerd aan lezen of spellen, maar het functioneren op handvaardigheid, balvaardigheid en balans was significant geassocieerd met de prestaties op rekenen. Wij vermoeden dat verschillen in corticale bijdrage aan rekenen en subcorticale bijdrage aan lezen en spellen in kinderen met een verlaagd IQ aan de basis liggen voor de gevonden verbanden tussen motorisch functioneren en rekenen.

In hoofdstuk 5 is het kwalitatief motorisch functioneren van kinderen die regulier onderwijs volgen en waarbij aangenomen wordt dat hun IQ in de normale range ligt, onderzocht met de TGMD-II. In dit hoofdstuk werd de relatie tussen motorisch functioneren en cognitieve flexibiliteit, als maat voor cognitie, onderzocht. Cognitieve flexibiliteit is de vaardigheid om het gedrag aan te passen aan de vereisten van de omgeving; problemen met deze vaardigheid kunnen duiden op neuropsychologische stoornissen zoals leerproblemen of ADHD. Er bleken significante verbanden te bestaan tussen het niveau van locomotorisch functioneren en object controle enerzijds en anderzijds mate van cognitieve flexibiliteit. Het gevonden effect voor locomotorisch functioneren was matig terwijl het effect van object controle op cognitieve flexibiliteit matig tot groot was.

In hoofdstuk 6 werd wederom de relatie tussen motorisch functioneren en cognitieve flexibiliteit bij kinderen op het reguliere onderwijs onderzocht maar nu in combinatie met het niveau van fysieke fitheid. Voorgaand onderzoek (en dit proefschrift) heeft al vastgesteld dat er een relatie tussen motorisch functioneren en cognitie bestaat alsmede een relatie tussen fysieke fitheid en cognitie. De resultaten van dit hoofdstuk laten zien dat de mate van object controle en fysieke fitheid simultaan samenhangen met cognitieve flexibiliteit, waarbij het effect van de motorische vaardigheid object controle 2 maal zo groot was als het effect van fysieke fitheid. Locomotorische ontwikkeling bleek alleen indirect, via fysieke fitheid, samen te hangen met cognitieve flexibiliteit. Deze resultaten zijn interessant voor onderzoekers die een interventie programma voor kinderen zouden willen ontwerpen om cognitie te verbeteren. De uitkomsten suggereren dat een interventie zich niet alleen op motorische vaardigheden moet richten maar ook op het verbeteren van de fysieke fitheid.

In hoofdstuk 7 worden de bevindingen en implicaties van dit proefschrift besproken.

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Acknowledgement (dankwoord)

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Biography

About the author

After receiving his Master's degree in Child Neuropsychology at the Vrije Universiteit in Amsterdam in 2005, he began working for a Pediatric Emergency Unit in Amsterdam where he worked for four and a half years. In 2007, he started his PhD project in Groningen in combination with a teaching position teaching advanced statistics (structural equation modeling and multilevel analysis) to the Master course of Human Movement Sciences.

During this time he also became involved in a research project dedicated to the study of rare neurodevelopmental disorders including Marshall-Smith syndrome and Pitt-Hopkins syndrome and he was involved as a statistical advisor in a research project at the addiction institute in Amsterdam.

In 2010 he returned to the Vrije Universiteit in Amsterdam (at the department of Clinical Neuropsychology) for a teaching position which included teaching Research Methods to first year bachelor students and providing clinical patient demonstrations to third year bachelor students with an interest in neuropsychology.

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